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EDITORIAL NOTES.

THE Council of the Geological Society has this year made the following awards:—Wollaston Medal, Alfred Harker, M.A., LL.D., F.R.S.; Murchison Medal, John William Evans, D.Sc., LL.B., F.R.S.; Lyell Medal, Charles Davison, Sc.D.; Wollaston Fund, Leonard Johnston Wills, M.A., Ph.D.; Murchison Fund, Herbert Bolton, M.Sc., F.R.S.E.; Lyell Fund, Arthur Macconochie and David Tait.

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THE Foulerton Award of the Geologists' Association for the year 1921 has been given to Messrs. C. Davies Sherborn and Martin A. C. Hinton. Mr. Sherborn was for eight years (1890–7) secretary to the Association, and his work in connexion with Dr. A. Rowe's classic papers on the zones of the White Chalk of the English Coast is well known. Mr. Hinton wrote several important papers for the Proceedings of the Geologists' Association on the Pleistocene deposits, fossil Voles and Lemmings, and other subjects.

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IN continuation of our note in the last number on the distress in Cornwall we desire to call attention to the fact that geologists and mineralogists have now an opportunity of helping a good cause and at the same time of acquiring collections of Cornish rocks and minerals on very favourable terms. Arrangements have been made for the sale on behalf of the Fund of collections of local rocks and minerals, mainly collected by the miners themselves. Three different sets are on the market, namely, (1) Cornish rocks (these are mainly illustrative of the granites, their modifications and metamorphism), (2) Lizard rocks, and (3) Cornish minerals. The specimens are selected, named, and labelled under the supervision of Mr. E. H. Davison, which is a sufficient guarantee of authenticity and accuracy, and the prices of the collections are very moderate. We would urge all private collectors and curators of museums who do not already possess complete sets of Cornish rocks to avail themselves of this opportunity. All communications should be addressed to Mr. E. H. Davison, B.Sc., F.G.S., School of Metalliferous Mining, Camborne, Cornwall.

The Thirteenth Session of the International Geological Congress, long postponed owing to the war, will be held in Brussels from 10th to 19th August next. During this period papers will be read and discussed and there will be short excursions in the neighbourhood. Both before and after the formal session long excursions will be conducted by eminent Belgian geologists to all points of geological interest in the country. Some of these will cover much the same ground as visited by the Geologists' Association last summer, but there are many others of great attractiveness. Full particulars can be obtained from the General Secretary, M. A. Renier, Palais du Cinquantenaire, Bruxelles.

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Owing to the Christmas holidays the proofs of our January number had to be corrected very hastily: a slight error, owing to the omission of three words, unfortunately occurred in a review of the Bulletin on the Rocks of Essex County, Mass. (p. 45). The first sentence of the second paragraph should have read as follows: "The calc-alkali series ranges from granodiorite (68·94 per cent SiO_2) to gabbro-diorite *and hornblende-gabbro* (45·32 per cent SiO_2), etc." The latter figure was obviously too low for a gabbro-diorite.

ORIGINAL ARTICLES.

Dolomitization in the Carboniferous Limestone of the Midlands.[1]

By L. M. Parsons, M.Sc., D.I.C., F.G.S.

(PLATE IV).

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I. Introduction.

THE contents of this paper record the results of a detailed examination of certain extensive areas of dolomitization in the Carboniferous Limestone of the Midlands. During the period 1912 to 1914 the faunal succession in the Carboniferous Limestone bordering the Leicestershire Coalfield chiefly claimed my attention,[2] but many problems associated with dolomitization arose in connexion with that work and have been discussed in a previous paper.[3] Being thus introduced to a study of metasomatism which yielded interesting results in Leicestershire, I turned my attention to the larger Carboniferous Limestone outcrop in Central Derbyshire, where a considerable thickness of dolomitized beds awaited description. The question as to whether the dolomitization in Derbyshire affected material on similar horizons or exhibited other features analogous to those of the dolomitization of the Leicestershire outcrops afforded considerable scope for investigation. Additional incentive to this particular study lay in the fact that dolomitization in the Carboniferous Limestone of this country had not been treated as a principal theme, but had been briefly described in notes occurring in papers by various authors, whose main object was the elucidation of other problems such as faunal succession.[4]

The widespread dolomitization which this paper attempts to describe occurs in the Gratton, Winster, Matlock, and Brassington districts of Derbyshire. At other localities in the same county smaller local developments of dolomitic material, obviously of subsequent origin, occur, but these are not comparable with the massive apparently bedded material of the districts mentioned above, and no description of them is given.

[1] Part II of Thesis approved for the Degree of Doctor of Science in the University of London.

[2] Described in *Quart. Journ. Geol. Soc.*, vol. lxxiii, 1917, p. 84.

[3] "Dolomitization and the Leicestershire Dolomites": Geol. Mag., 1918, pp. 246–58.

[4] e.g. Sibly, *Q.J.G.S.*, vol. 1908, p. 54.

Since mapping is indispensable if the nature of metasomatism is to be fully appreciated, I have traced the dolomitization on the 6 in. sheets of the Ordnance Survey. Certain features of the maps, particularly lateral transitions and kernels of dolomite or of limestone, are obliged to be more or less diagrammatic, since it is impossible to show some of them true to scale. In mapping metasomatism, all parts of the surface within the boundaries should be examined in detail, and it is possible that some remnants of limestone or dolomite may have been overlooked.

The chemical composition may vary in an area of dolomitization, consequently the shading on the maps represents the type, dolomite, or dolomitic limestone, as the case may be, which predominates in any area.

In tracing changes of horizon I have found the zonal map of Mr. C. B. Wedd [1] to be of the greatest help in connexion with the study of the country east of Grange Mill. In the absence of a zonal map of the limestone west of Grange Mill, I have studied the fauna in the dolomitic material itself, and in the limestone adjacent to the dolomitized rocks. The results supply the information necessary concerning the horizons of the metasomatism.

Detailed zonal subdivisions are not shown by any method of shading on the maps, since the variable position in the sequence of chert in the country west of Grange Mill makes it inadvisable to give a map similar to that of the Matlock district by Mr. Wedd. The only differentiation possible in the neighbourhood of the dolomite is between D_1 and D_2, and the maps are less burdened by detail if such simple differentiation is expressed, where necessary, by the corresponding symbols.

Numbers representing altitudes are given, so that the relation between dolomitization and topography may be appreciated.

The Leicestershire Dolomites having been described previously, the present paper deals almost entirely with the Derbyshire material, but since the two districts exhibit such contrasting types of metasomatism, and as a comparison could not be made before the material in Derbyshire had been examined, I have given in the last section an outline of my conclusions with regard to the Midland Carboniferous area as a whole.

II. Note on Classification and Evidences.

A classification of magnesian rocks based upon chemical composition alone is unsatisfactory, and a simple classification based upon the time and mode of introduction of magnesia was given in my earlier paper. The recognition of the following more complicated types appears to be necessary:—

Complex dolomites or dolomitic limestones yielding evidences of more than one period of secondary addition of magnesia. Such

[1] *Mem. Geol. Surv.*: "The Geology of the Northern Part of the Derbyshire Coalfield and Bordering Tracts," 1913, p. 15.

rocks result from later alteration of either contemporaneous or subsequent dolomites.

Compound dolomites in which a primary clastic or precipitated dolomite has been produced by secondary addition of magnesia. It must be noted that types petrologically described under various terms such as dolomite-mudstone, pseudo-breccia, etc., will naturally fall into their respective groups in the classification arranged according to the time and mode of alteration.

The methods of investigation adopted in connexion with the Derbyshire material are essentially the same as those pursued in the case of the Leicestershire rocks. The evidences obtained from different series of phenomena converge toward definite conclusions. The different series of phenomena are those connected with (*a*) field relations, (*b*) inherent structural and mineralogical features, (*c*) the absence or presence and condition of fossils, (*d*) chemical analyses.

A general summary of evidences has been given previously, but additional criticism of certain evidences and amplification of others accompanies the description of the Derbyshire rocks.

The uniformity or variation in chemical composition of dolomitic rocks is a phase of the subject which has scarcely received the attention it deserves, and in the present work I have made an attempt to develop this side of the question.

III. The Dolomitic Limestones and Dolomites between Gratton Dale and Cromford.

The tectonics of the limestone area between Cromford and Gratton Dale are relatively simple in the Gratton Dale district, but become more complicated eastwards in the neighbourhood of Matlock Bath, where there is a series of anticlinal and synclinal folds worked out in detail by Mr. C. B. Wedd.[1] With the exception of the lower sequence in Gratton Dale and Longdale, described separately, none of the D_1 beds between Gratton and Cromford exhibit dolomitization, but in the D_2 strata north and east of the lower lava dolomitic material occurs in two extensive areas situated in the neighbourhood of Winster and of Matlock Bath respectively.

Field Relations.

The dolomitization has attained its greatest vertical and lateral development in the vicinity of Winster. Near Bonsall Moor Farm occurs a well-marked escarpment of dolomitic limestone, just above the lower lava. Northwards the metasomatism extends below and above the upper lava to a position beyond the Wensley road and not far below the Pendleside Shales. Apparently nearly all the D_2 beds, and possibly part of the D_1 material here consists of dolomitic limestone. A little further to the east, beyond Bonsall Moor Farm,

[1] *Mem. Geol. Surv.*: "The Geology of the Northern Part of the Derbyshire Coalfield and Bordering Tracts," 1913.

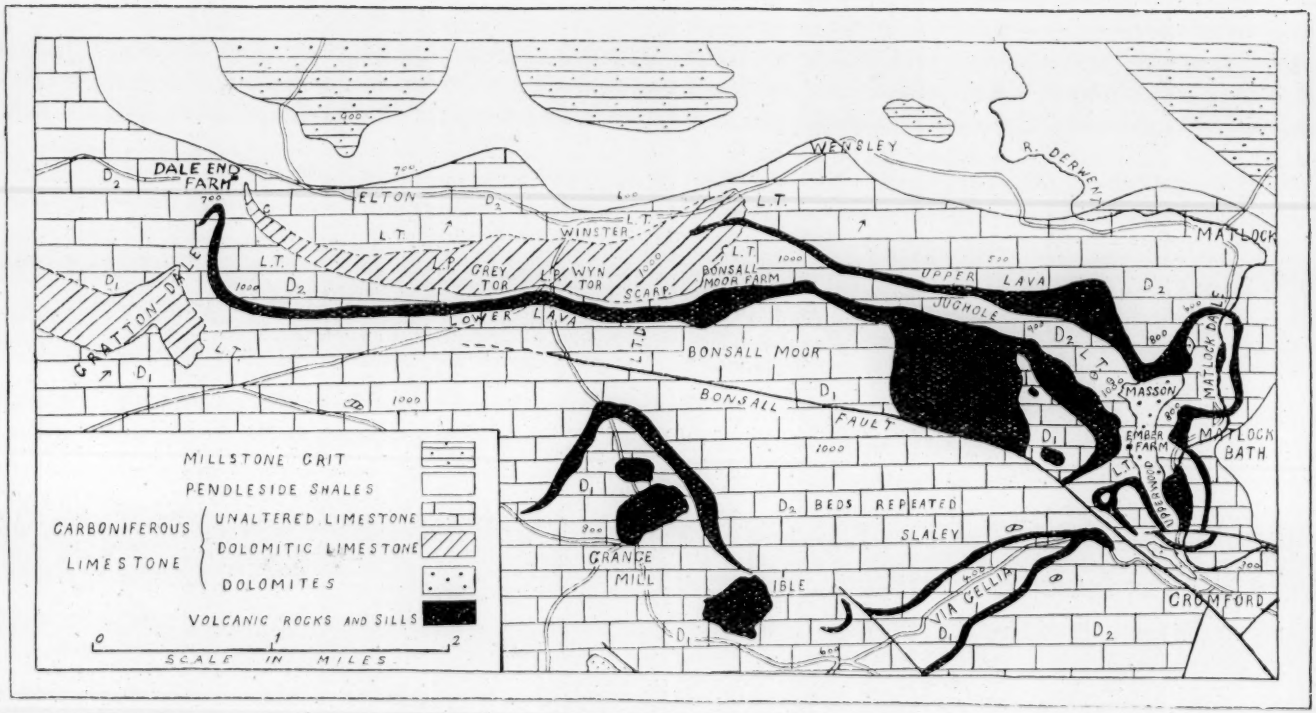

FIG. 1.—Geological map illustrating Dolomitization in the Limestone between Gratton and Cromford. Lines from the maps of the Geological Survey, Pseudo-strata of metasomatism, by L. M. Parsons.

the dolomitic beds are abruptly replaced by normal limestones, but the actual lateral transitions of dolomite into limestone are obscured. On the maps the symbol L.T. represents such transitions obscured by vegetation or by cultivated land. Actual visible passages from dolomite into limestone are represented by L.P., and where the material which must have contained the transition has been denuded the symbol L.T.D. has been employed. At various positions near Winster masses and stacks of dolomitic limestone form prominent land-marks known locally as tors. Westwards beyond the Grey Tor the width of the outcrop of material affected by dolomitization becomes less, though the dip of the beds remains about the same. The beds on the horizon of the Winster escarpment have westwards passed into normal limestones within a distance of $1\frac{1}{2}$ miles. Similarly some of the higher strata not far below the Pendleside Shales are dolomitic towards Wensley, but have become normal limestones a little west of Winster, a distance of about 1 mile. Further towards Gratton Dale the area of metasomatism becomes greatly attenuated and finally dies out near Dale End Farm. Concerning the dolomitic area from Bonsall Moor Farm to Gratton Dale as a whole, several important facts should be summarized; nowhere is the vertical[1] passage of limestone into dolomite or dolomite into limestone actually seen. The lateral passages are also generally obscured, but exceptions to this occur at Gratton, Westhill Farm, and Winster.

At Winster, opposite the inn called the "Miners' Standard", are small disused quarries containing cherty beds, showing rapid transitions of dolomite and limestone, the patches of the latter being usually a yard or two in length. A striking tectonic feature is the absence of faulting in all of the beds north of the lower lava. The Bonsall fault south of the lava throws some light on the probable southward extension of some of the dolomitic limestones of Winster. Between the lower lava in the Via Gellia and this fault considerably more than 100 feet of D_2 strata, all non-dolomitic, have been brought down and the upper beds must be the southern extension of the lower dolomitic limestones to the north. The material containing the southern transition from dolomite into limestone must have existed above the lower sequence in the intervening space, but has since been removed by denudation.

Eastwards all of the dolomitic beds appear to pass into limestone within a short distance. Westwards all of the dolomitic material has become limestone at Gratton Dale, $2\frac{1}{2}$ miles from the Winster escarpment. The more rapid lateral transitions occur on the lower and higher horizons, while in the middle of the D_2 sequence the metasomatism has been more persistent.

From these considerations of field evidences it is obvious that the Winster area of dolomitization is a true outcrop in the petrological

[1] i.e. up or down the sequence.

sense, but not a normal outcrop stratigraphically. Since we are concerned with a problem essentially connected with bedded material having definite horizons, it may be convenient to employ the term *pseudo-strata* to denote any area of dolomitization in which the metasomatism either changes from one horizon to another or fails to persist along a definite horizon. Some distance eastwards from Bonsall Moor Farm all the beds between the two lavas consist of non-dolomitic limestones extending via Jughole Wood towards Masson Hill. For a distance of about 3 miles normal limestones have entirely replaced dolomitic material of Winster on the west and of Masson Hill on the east. Here is one of the most marked lateral transitions in the district. Near Jughole Wood, as everywhere east of Wensley, none of the limestones above the upper lava exhibit any traces of dolomitization, and at Jughole the contact of the lava with the normal limestones below is well seen. Further south-east, as Masson Hill is approached, patchy dolomitization makes an appearance between the two lavas, while on the heights of Masson itself a considerable thickness of dolomite is seen underneath and in contact with the upper lava. In Matlock Dale the beds are brought down to the river by folding, and in the quarries near the river normal limestones are seen immediately under the upper lava. Here is another striking lateral transition of dolomite on Masson Hill into limestone in the valley below. It is a curious fact that with the exception of the Upperwood Slopes further south, no dolomitic material comes down into the valley, though the beds are repeatedly brought down and taken up again by folding. Apart from small dolomitic patches, the limestones on all horizons on the eastern side of the river are devoid of dolomitization. On the western side of Masson Hill the metasomatism changes from the beds immediately below the upper lava to a lower horizon. Southwards from Masson the dolomitic area extends past Ember Farm, towards the Upperwood Slopes.

The metasomatism changes horizon gradually as far as Ember Farm, where it has descended to within a short distance of the lower lava. South of this farm, however, the dolomitization leaves the lower beds and the lower boundary of metasomatism rapidly ascends the sequence. Probably nowhere else in the whole area does the pseudo-strata exhibit such a steep horizon gradient. At Upperwood the beds dip towards the river, and the dolomitization extends into the valley, attaining here its greatest vertical extent in the immediate neighbourhood of Matlock, all of the beds between the two lavas being affected. The ground further south is largely overgrown and the metasomatism is traced with difficulty.

Inherent Structural and Mineralogical Features.

Megascopic Characters.

The material of the Tors and of the escarpment near Winster consists of massive blocks and stacks of rock often several feet

thick, in which bedding planes are often traced with difficulty. The material on the same horizons in the main dale at Gratton and around Jughole Wood consists of thinly bedded limestones, in which the planes of stratification are well marked, hence the process of dolomitization has welded material originally thinly bedded into more massive blocks. In the whole district between Gratton and Cromford it is found generally that wherever dolomite passes laterally into limestone the latter exhibits thinner bedding and more distinct stratification than does the former.

Streaks and patches of dolomite, which, for convenience, may be termed *dolomitic epiphyses*, and extensive patchiness on a large scale, features more or less associated with typical vein dolomitization, if present, are obscured. Only at one locality have I found anything approaching clearly marked pseudo-brecciation or patchiness on a small scale. At Winster occurs a rock consisting of light yellow patches alternating with dark grey areas, both yellow and grey patches usually measuring 1 or 2 inches across. Microscopic and chemical examinations show that both light and dark portions consist of minutely granular dolomite. The grains are mainly allotriomorphic and exceedingly small, the average diameter of a grain being about 0·02 mm. The patchiness is not due to any differential [1] dolomitization, but to variable limonitization. The remarkably small size of the dolomitic grains and their allotriomorphism might be considered to indicate that this rock may be a dolomitic mudstone of primary clastic origin, but if such were the case it would be difficult to explain its lateral non-persistence in the area. Certain megascopic features bearing relation to porosity must be considered here. The dolomitic material of Gratton, Winster, and Matlock (also that in the Harborough area described later) weathers with a characteristic vesicular structure. These cavites vary from a fraction of an inch to several inches across, and appear to be surface phenomena only, since recently worked material in quarries at Winster and near Elton shows none of the vesicular structures. It seems a legitimate conclusion that the vesicular exterior is produced by the removal of free calcite in the usual processes of sub-aerial denudation. This differential weathering appears to depend upon there being sufficient but not too much free calcite.

Microscopic Characters.

The bulk of the dolomitic material exhibits moderately idiomorphic crystals varying in size between a minimum width of 0·08 mm. and a maximum width of 0·7 mm. Pl. IV, Fig. 1, from a specimen taken from the Winster escarpment, illustrates the typical structure

[1] In this paper the term "differential" applies to dolomitization which has differentiated between certain portions of rock because of variations in texture or mineral constitution. The term "selective" is restricted to cases in which the differentiation is between matrix on the one hand and organic structures on the other.

composed of some idiomorphic crystals together with a large number of rather allotriomorphic grains. Considerable variation in size is also shown. Since much of the material is rather allotriomorphic, the dimensions given here and in the table refer to the largest diameter of grains or to the larger diagonals of rhombohedra.

TABLE ILLUSTRATING VARIATION IN SIZE OF GRAIN OF DOLOMITIC MATERIAL BETWEEN GRATTON AND CROMFORD.

Locality.	*Minimum.*	*Maximum.*	*Common Size.*
	mm.	*mm.*	*mm.*
Gratton D_2 . .	·1	·7	·25
Gratton D_2 . .	·09	·6	·20
Grey Tor . .	·08	·2	·125
Wyn Tor . .	·125	·45	·15
Winster Scarp .	·125	·6	·2
Winster Scarp .	·08	·15	·12
Winster Pseudo-Breccia . .	(remarkably uniform)		·02
Masson Hill . .	·09	·5	·25

The question arises as to whether size and allotriomorphism in themselves yield reliable evidence of origin.

Mr. E. E. L. Dixon has found that certain contemporaneous dolomites in the Swansea area are composed generally of much smaller grains or crystals than those forming subsequent dolomitic material occurring in the same district.[1] This author gives the maximum size of grains in the *laminosa* dolomites (contemporaneous) as 0·01 inch in length of side. This approximately corresponds to a maximum diagonal of ·375 mm. In the case of the Swansea subsequent dolomites the *average* length of side of their rhombohedra is given as 0·02 in., corresponding to a larger diagonal of ·7 mm. If these dimensions are compared with those given in the table above, it will be seen that the Winster and Matlock material is commonly composed of grains smaller than the maximum of the Swansea contemporaneous dolomite, and considerably smaller than the average size of grains in the Swansea subsequent dolomites. If we accept the field evidences indicating that the Winster material is of subsequent origin, it is clear that subsequent dolomites in one area may be composed of grains as small as those composing contemporaneous dolomites in another area.[2]

The nature of the original limestone is a factor of considerable importance in the questions of relative idiomorphism and size. The transition limestone at Winster (see Pl. IV, Fig. 2) shows that the original limestone there probably consisted of a mass of minute organisms, sponge spicules, foraminifera, etc., embedded in a fine-grained matrix almost completely non-recrystallized. The metasomatism at Winster has evidently led to a considerable increase in size of grain, and in this respect bears out observations of Van Tuyl.

[1] *Mem. Geol. Survey*: "The Geology of the South Wales Coalfield: The country around Swansea," 1907, p. 16.

[2] See also researches of Van Tuyl, *Iowa Geol. Survey*, vol. xxv, p. 395.

With regard to impurities, hæmatite is relatively uncommon, and occurs merely as surface stains associated with recent weathering. Limonite is more common, and is typically interstitial, but certain specimens, particularly some from Gratton, exhibit zonal inclusions of limonite in dolomite crystals. Pl. IV, Fig. 3 shows two distinct phases of dolomitization. The wall of the coral (*Lithostrotion portlocki*), a portion of the interior, and parts of the matrix are replaced by fine-grained dolomite free from zonal growths, but the matrix mainly consists of dolomite larger in texture and containing many central or zonal limonite inclusions. The inference that the dolomitization of the coral occurred at a different period from that of the limonite-bearing portion of the matrix appears to be legitimate.

At Gratton and other localities two (or perhaps more) periods of metasomatism have produced dolomitic rocks which may be described as *complex-subsequent*.

Pl. IV, Fig. 3 also illustrates certain features of "selective" dolomitization. A considerable portion of the interior of the coral is occupied by coarsely recrystallized calcite. General examination of the slide and hand-specimen shows that coral structures are partly replaced by fine-grained dolomite and partly obliterated by the recrystallized calcite. Most of the matrix consists of the coarser limonite-bearing dolomite. These features indicate three distinct phases of alteration :—

(1) The recrystallization of portions of the coral and intervening spaces.

(2) Dolomitization of the coral tissues and perhaps a portion of the matrix. (There is nothing to indicate whether or not the coral tissues had been previously recrystallized by calcite of a finer grain.)

(3) Simultaneous dolomitization and limonitization of the larger part of the matrix.

It is very probable that (1) preceded (2), but it is difficult to say whether the bulk of the matrix was altered before or after the dolomitization of coral structures.

The transition limestones of Winster (Pl. IV, Fig. 2) and of Jughole (Pl. IV, Fig. 4) show that a matrix mostly non-recrystallized is a striking feature of the unaltered limestone in these D_2 beds. It might be assumed that, in the case described above, the matrix was dolomitized before the organic structures. But conclusions from "selective" phenomena must be made with care, and as a discussion of this matter was given in my earlier paper it will be sufficient if it is stated here that features observed in Derbyshire fully confirm my opinions expressed at that time. At Winster and Gratton both corals and matrix are often found equally dolomitized. In some of the Gratton specimens I have found that the dolomitization has affected the matrix more than coral structures. Thus, in the district under consideration, selective phenomena vary considerably in material taken from exposures along similar horizons

and separated only by short distances. It is, of course, quite probable that selective features may be consistent in one area but contradictory in another. Such features appear to depend as much on some inherent factor in the original limestone as upon the time and mode of dolomitization.

Many of the beds in the Winster district contain chert, and sections across the junction of chert and dolomite show that the latter is not included in the former. From this it appears that silicification occurred before dolomitization.

One other feature must be mentioned. Where the dolomitic material is seen immediately underneath the upper lava, on Masson Hill, for instance, metamorphic effects are not present in the dolomite. Although the lava might fail to produce alteration in a contemporaneous dolomite underneath, it is far more likely that the absence of metamorphism is due to the dolomitization having taken place at some subsequent period.

In passing it must be noted that the absence of metamorphism in a dolomite resting on a lava yields no evidence of either contemporaneous or subsequent alteration. Metamorphic effects or their absence in dolomite in contact with a sill would be more helpful, but the limestones in contact with the sills in the Matlock area consist of undolomitized beds mainly of D_2 age.

The majority of the structural features described above indicate subsequent dolomitization, and thus support the evidences afforded by field relations.

Condition of Fossils.

Very little need be said under this heading. The presence of a rich fauna containing numerous corals negatives the probability of primary precipitation, but the condition of coral and other fossils is so varied in different parts of the dolomitic material that no satisfactory conclusion with regard to either contemporaneous or subsequent dolomitization can be drawn from the condition of organic remains. Contradictory selective phenomena on a large scale occur very similar to those on a microscopic scale described above.

Chemical Analyses and Porosity.

Numerous analyses of the material between Gratton and Cromford show that in composition the dolomitic limestones of Winster differ in many respects from the dolomite of Matlock. At Winster the bulk of the material consists of dolomitic limestones in which the proportion of magnesium carbonate is variable and usually small; though material occurs in the escarpment and the Wyn Tor having a much higher proportion of $MgCO_3$. Near Matlock the bulk of the material of Masson and Upperwood consists of dolomite having 40 per cent or more of $MgCO_3$, and although some of the portions analysed have yielded a smaller proportion than this, the composition is generally much more uniform than that of the Gratton and

Winster material. Differences in composition, specific gravity, and porosity are indicated in the following table, compiled from analyses of typical specimens.

TABLE SHOWING VARIATION IN CHEMICAL COMPOSITION, SPECIFIC GRAVITY, AND POROSITY OF DOLOMITIC MATERIAL BETWEEN GRATTON AND CROMFORD.

Locality.	$CaCO_3$	$MgCO_3$	Fe Comp.	Residue.	S.G.	S.G. of Powder.	Porosity.	Per cent of Mg ÷ Poros.
Gratton . .	78·6	15·3	3·7	2·4	2·55	2·73	6·4	2·4
Gratton . .	79·4	13·9	4·8	1·9	2·65	2·76	3·9	3·6
Grey Tor . .	83·4	9·9	2·3	4·4	2·72	2·81	3·2	3·09
Grey Tor . .	78·4	9·6	7·9	4·1	2·71	2·82	3·9	2·46
Wyn Tor . .	58·5	38·0	2·0	1·5	2·38	2·61	8·8	4·32
Wyn Tor . .	84·5	10·7	1·1	3·7	2·69	2·75	2·2	4·86
Scarp. Winster. .	61·5	34·3	1·4	2·8	2·39	2·78	13·9	2·46
Masson Hill .	49·0	43·7	1·9	5·4	2·45	2·70	5·8	7·52
Masson Hill .	54·2	41·1	0·8	3·9	2·52	2·67	5·6	7·32
Upperwood. .	51·5	40·2	1·25	7·1	2·53	2·69	5·9	6·81
Upperwood. .	52·4	43·6	2·1	1·9	2·43	2·59	6·2	7·03
Black Tor . .	84·3	9·3	1·2	5·2	2·58	2·64	2·3	4·05
Tran. 1st Winster.	97·6	Minute trace	Small traces	2·4			negligible	
,, Jughole	97·3	None	,,	2·7			,,	
,, Matlock (Whittaker's)	98·1	,,	,,	1·9				

As far as one can say from the specimens analysed, the greatest variation appears to be in the vicinity of the Wyn Tor. The considerable variation in the proportion of magnesium in the material between Gratton and Winster certainly suggests subsequent metasomatism, and although the chemical evidence of the Matlock material might support the theory of contemporaneous alteration, the field and inherent structural evidences are quite against such an explanation. It appears that three distinct modes of metasomatism may produce material having fairly constant chemical composition. The same conditions which favour the formation of extensive bedded dolomites would in all probability result in the material having a reasonably uniform composition over considerable areas. This would particularly be the case with primarily precipitated dolomites, and might generally be the case, though perhaps not so pronounced, in the contemporaneous alteration of bedded material. Thirdly, nearly complete subsequent dolomitization affecting a relatively small area could produce a constant composition, and I regard the Matlock dolomitization as an example of this type.

If results of analyses are plotted graphically, the relative proportion of magnesium and calcium at any locality can be seen at a glance, and the *dolomitic gradient* or rate of increase in magnesian contents per unit distance can be appreciated. Near the Grey Tor, Winster,

there is a steep gradient, whereas there is hardly any gradient in the Masson and Upperwood material.

Porosity has been determined in the following manner—a moderately large specimen from each locality was thoroughly dried and weighed. Then it was completely coated with a thin layer of paraffin wax to prevent water entering the pores and again weighed. The difference in the two weights gave the weight of the wax. The specific gravity of the specimen was then found in the usual way, the necessary corrections being made to allow for the wax. Next the wax was removed by immersion in hot water. The specimen was again dried, finely powdered, and the specific gravity of the powder determined by means of a specific gravity bottle.

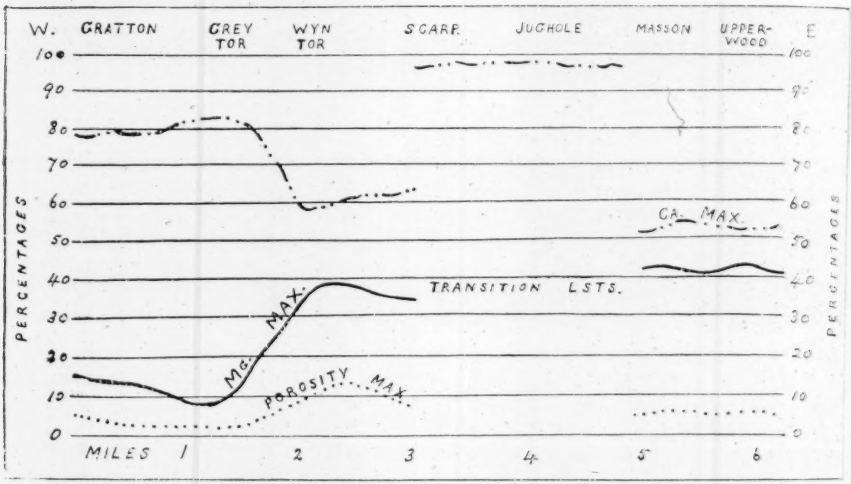

FIG. 2.—Graphs illustrating variation in chemical composition, dolomitic gradients, and porosity in the material between Gratton and Cromford.

From the data thus obtained the porosity was calculated as a percentage by using the formula :—

$$\text{Porosity} = \frac{100\,(D - d)}{D}$$

where D = specific gravity of powder
and d = specific gravity of original lump inclusive of pores.

Experiments on porosity appear to be helpful in connexion with the question of leaching by surface waters.[1] The porous nature of the dolomitic material compared with that of the transition limestones indicates that extensive leaching has occurred in the dolomitic parts only, and the inference is that the process of dolomitization has so reconstituted the rock that the removal of residual calcite has been thereby facilitated.

[1] The porosity is only partly explained by molecular contraction due to dolomitization.

PERCENTAGES

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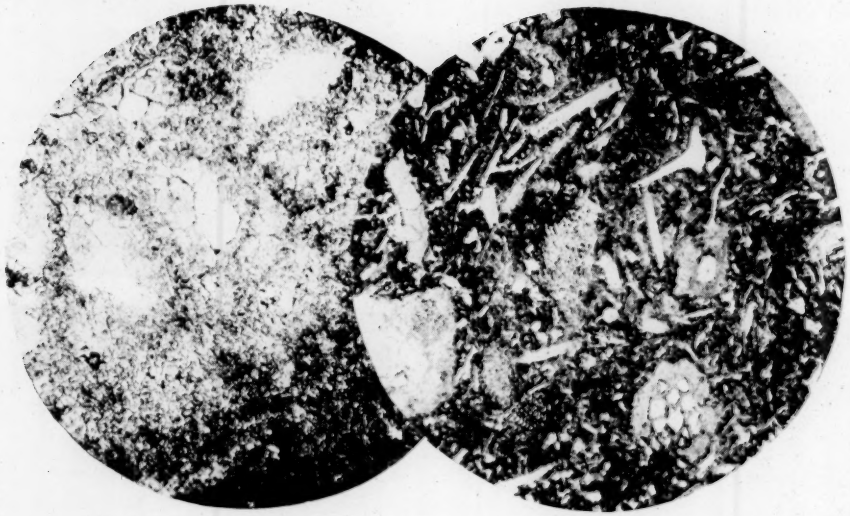

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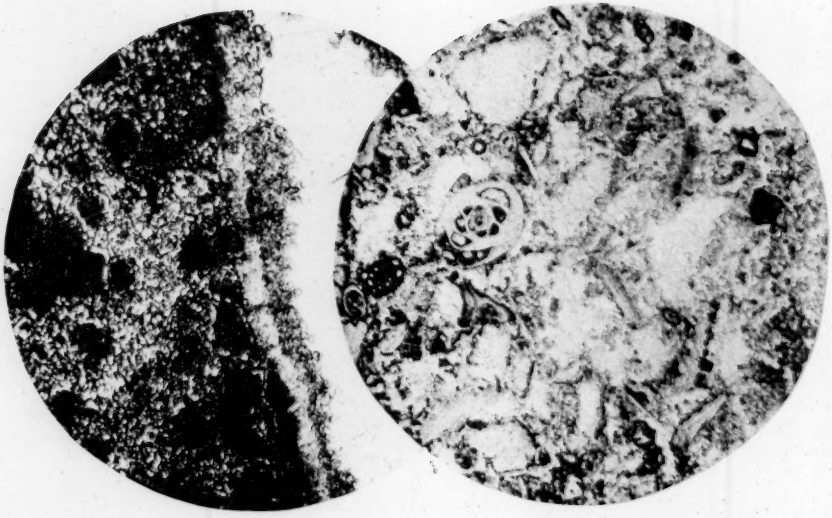

G. S. Sweeting, photomic.

DOLOMITIZED LIMESTONES, DERBYSHIRE.

To face p. 63.

If considerable leaching has occurred in dolomitic material of uniform composition, then

$$\frac{\text{percentage of } MgCO_3}{\text{porosity}} = \text{a constant (approximately).}$$

This holds true whether later infiltration has introduced calcite, iron oxide, etc., or not, since the introduction of such materials decreases both the proportion of $MgCO_3$ and the porosity. In the case of the dolomite of Masson and Upperwood,

$$\frac{\text{percentage of } MgCO_3}{\text{porosity}}$$

gives a fairly constant figure, and the inference is that the dolomitization was fairly uniform prior to leaching. But in the case of the Gratton to Winster dolomitic limestones having a variable proportion of $MgCO_3$, a similar constant is not obtained though the various specimens are obviously porous and give considerable porosity results, hence leaching in originally variable dolomitic material is indicated.

The field relations and inherent structures of both the Winster and Matlock materials prove conclusively the subsequent nature of the dolomitization. Palæontological features yield no satisfactory evidence. The results of chemical analyses support the theory of subsequent alteration in the case of the Winster area, but not so definitely with regard to the Matlock material. That magnesian ground waters of different dates have produced the metasomatism is, I think, the most satisfactory solution, since marine influences or those of pneumatolysis are not indicated by the evidence. While such appears to be the mode of magnesiation, the actual source of the magnesian factor remains problematical. The Permian Magnesian Limestone, which probably extended much further westwards than its present outcrop, may have supplied the magnesium, but suggestions of this kind can be only of a speculative nature.

EXPLANATION OF PLATE IV.

FIG.

1.—Dolomitic limestone, escarpment east of Winster. × 23. Generally rather allotriomorphic. Coral structures (left) show larger dolomite crystals than those in the matrix. Other parts of this slide exhibit this feature reversed, larger crystals in the matrix.

2.—Transition limestone, quarry opposite the Miners' Standard, Winster. × 21. Sponge spicules form a considerable part of the rock.

3.—Dolomitic limestone, D_2 beds, Gratton Dale. × 23. The matrix (left) consists largely of dolomite having zonal inclusions of limonite, while the coral structures (right) are in dolomite free from such limonite inclusions. Recrystallized calcite occurs in the spaces within the coral.

4.—Transition limestone Jughole Wood, West of Matlock. × 23. Matrix mainly non-recrystallized.

(*To be continued.*)

On the 60-ft. Raised Beach at Easington, Co. Durham.

By David Woolacott, D.Sc., F.G.S.

(PLATE V.)

An excellent exposure of a Raised Beach has lately been discovered at Easington.[1] This deposit, in my opinion, forms a part of the beds of sand, gravel, conglomerate, and breccia which are exposed along this part of the Durham coast for at least 5 or 6 miles, and which were described by me as Raised Beaches in 1905.[2] I also consider that the upraised littoral formations were produced in late Pleistocene times.

All geologists who have examined the exposure—including G. W. Lamplugh, F.R.S.,[3] Dr. Trechmann,[4] E. Merrick, M.Sc., L. Hawkes, M.Sc.—are agreed that it is undoubtedly a littoral formation, and although there may not yet be complete agreement as to the exact age or extent of this deposit, yet there can be no question that it must be taken into account in any discussion of the Glacial and Post-Glacial formations of the East of England. There is nothing very remarkable in Raised Beaches at such a level, nor in the amount or nature of the movements that produced them; their importance lies more in connexion with the origin and method of deposition of a large portion of the sands, gravels, and clays that occur above the true boulder clay (or moraine profonde of the ice-sheets) along the coastal region or up the buried Pre-glacial valleys of the east of England than in the deposits or uplifts themselves.

The section has the chief characters we expect to find in such exposures typically preserved, and these can be easily examined. It occurs on the south-east flank of Beacon Hill, about half a mile north of Easington station, and can be clearly seen in a steep foot-path (the top of which is marked by a stile) leading down to the shore at this point. The photographs published with this paper give a clear idea of the nature of the deposit, as far as it can be conveyed by photographs; the features proving its direct marine

[1] A short description of this deposit was given in the Geological Magazine, vol. lvii, 1920, p. 307.

[2] "The Superficial Deposits and Preglacial Valleys of the Northumberland and Durham Coalfield": *Quart. Journ. Geol. Soc.*, vol. lxi, 1905, pt. 1, and map, pl. ix, p. 94.

[3] I consider that this geologist, who evidently thoroughly appreciated the importance of the occurrence of high-level Raised Beaches in Durham, was quite justified when he asked me to be cautious in accepting the evidence for their existence (see discussion, *Geographical Journal*, July, 1907, p. 56).

[4] I also think that until the Easington depcsit was discovered, Dr. Trechmann, in speaking of the beds along the coast of South Durham, had complete justification for stating "that he did not see the necessity for assuming these gravel deposits of marine origin" (*Q.J.G.S.*, vol. lxxi, pt. i, 1915, p. 75). I had, however, definite evidence in 1900–6 of a Raised Beach at a higher level in north-east Durham, and had made in 1903–4 a detailed examination of the course of conglomerate to the north and south of Easington, which had convinced me of its origin. (I do not think that the path that cuts through the Easington deposit existed at that time.)

origin are, however, much more striking in the field. It is undoubtedly a bed laid down on the margin of the sea, and is in situ. It has not been carried by ice into the position in which it occurs, nor has it been reassorted since its deposition on the ancient shore.

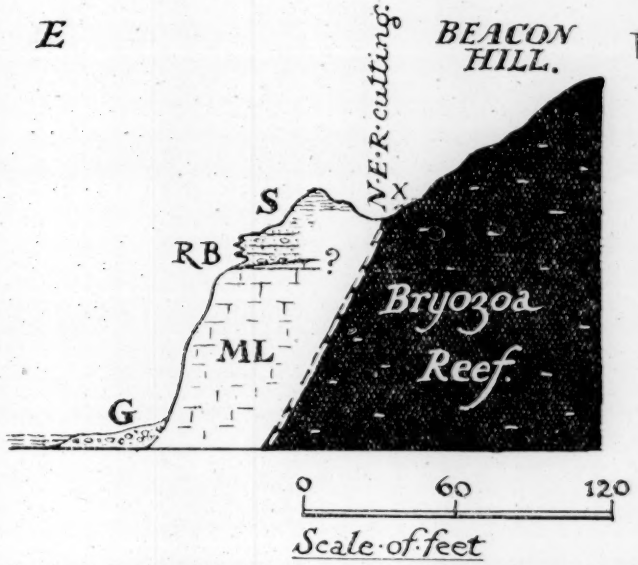

FIG. 1.—Section of the cliff at Easington showing the position of the Raised Beach. M.L. Middle Magnesian limestones and breccias—the eastern equivalents of the fossiliferous Reef which forms Beacon Hill. R.B. The 60 ft. Raised Beach resting on the rock-platform, which probably rises slightly as it passes beneath the deposit. S. In a cutting made in the face the calcreted gravels were proved to be 15 feet in thickness, covered by a thin deposit of soft sand with shell fragments, above which was reassorted boulder clay (Common Clay), the whole being covered by washed soil. X. Calcreted gravels in the railway cutting which have a regular upper limit and are probably marine. G. Present-day shingle.

The more interesting features of the deposit are (1) it rests on a horizontal platform of Middle Magnesian Limestone at about 60 feet above sea-level (Figs. 1 and 2). At one part on the south side of the path the shelf has been bored by a small boring organism, and there can be no doubt that it is a real wave-cut terrace. This platform can be distinctly followed both ways (Plate V, Fig. 2), and can be seen to pass in the latter direction from rock on to true boulder clay (Fig. 2), when it becomes less uniform and distinct.[1] (2) The

[1] It is important to notice that the platform must have been cut on boulder clay. This clay is the Main or British Drift of this coast containing Lake District and Cheviot erratics. Even if the Raised Beach is restricted to the narrowest limits, yet the platform must have been cut on boulder clay.

deposit, which is at least 15 feet thick,[1] consists of two parts, which are best seen on the north side of the path, a lower one of loose sand and large pebbles, and an upper of horizontally-bedded and firmly-calcreted conglomerate. In the lower layers numerous bored stones occur. It contains, along with other rocks, numerous large and small fragments of Magnesian Limestone, which are bored by *Saxicava* (the shells of which sometimes occur in the holes), and by *Cliona* and *Polydora*. Quite a considerable proportion of this division of the deposit is formed of these bored pebbles. (3) Also in the lower part numerous specimens of small and large, whole and broken, shells occur, sometimes with their colour and markings beautifully preserved. They include many of the common shells of the present seashore—the periwinkle and the limpet, etc.—and as far as the fauna has been examined there is nothing to show that the climate was different from that of the present day.[2] Foraminifera also occur in the sand. The species of Mollusca occurring in the deposit include :—[3]

Littorina littorea	*Buccinum undatum.*
Littorina rudis	*Cyprina islandica*
Littorina obtusata	*Mytilus edulis.*
Patella vulgata	*Ostrea* sp.
Purpura lapillus	*Rhynchonella psittacea.*
	Saxicava sp.

The commonest species are *Littorina obtusata*, *Patella vulgata*, and *Littorina littorea*. It is a typical littoral fauna with the exception of the *Rhynchonella*, of which one specimen of a dorsal valve has been collected.

In the upper cemented part the shells are scarcer, but some, including one or two whole *Patellas*, can be seen in the face of the conglomerate. A portion of the shell of a *Pecten* was collected from the upper beds. This part of the deposit is more difficult to properly examine. The shells are not so clearly seen nor so well preserved nor so easily extracted.[4] The strongly calcreted nature of this conglomerate, and the fact that it contains fewer bored rocks and shells, are of interest, because it is the more usual type of the deposit to the north and south of Easington. The beds at this point appear to have been laid down in a sheltered bay under fairly tranquil

[1] About 10 feet can be clearly seen in the section, but its thickness (allowing that the platform runs back horizontally) has been proved by a cutting made in the face above it to be 15 feet. The bedded gravels are this thickness, being overlaid by a few inches of soft sand containing shell fragments, above which is a reassorted boulder clay. Calcreted gravels with a level upper limit can be seen in the railway cutting above at about 90 feet. The writer is of the opinion they are marine, although it is difficult to prove this; it is also uncertain whether they are continuous with the gravels and sands below.

[2] A collection of shells from this deposit has been placed in the Sunderland and Newcastle museums.

[3] My determination of the forms has in most cases been verified by Dr. Trechmann or Mr. Iredale, of the British Museum.

[4] At one part two or three shells of *Helix* are cemented in.

conditions, hence the greater accumulation of bored rocks, shells, and shell-fragments, and their more distinctly bedded nature than is usually the case in other exposures of them along the coast. All the features of a typical raised beach appear to be combined here. It is obvious that a great quantity of the Glacial deposits must have been denuded to form these beds, and it thus seems probable that one of the reasons for the unequal distribution of the shells in them is that where the boulder-clay was being most eroded the water would be muddy and the life of the shore scarcer, and another is that the beds that are exposed were not always deposited on a rock platform, but on boulder clay, and the accumulations of material in these areas must have been very loose and coarse. In such conditions and in such material whole shells are not likely to be preserved. It is, however, probable that the rock platform is buried beneath and behind the deposits exposed along the coast, and that the raised beach characters would always be more definite on this ledge. (4) The pebbles, of which the conglomerate at the particular point discussed is formed, are generally distinctly water-worn, but some are more or less angular. In it there are fragments of Magnesian Limestone, quartz, quartzite, flint, sandstone, granite, olivine-basalt, Volcanic Series of Borrowdale from the Lake District, and porphyritic lava from the Cheviots. It is perhaps worthy of note that the Cheviot and Lake District rocks occur in the loose, sandy base of the deposit as well as in the calcreted part above. About fifty per cent of the rocks are foreign to the district, and have, in my opinion, been derived from the denudation of the Glacial deposits of the area. There is no evidence that any have been brought to the point by floating ice, but even if it is allowed that some have, yet it is evident that the Firth of Forth, Lake District, and Tweed-Cheviot ice must have been occupying part of the east coast at the time. The writer is of the opinion that the deposit is definitely later than the formation of the Main or British boulder clay. The conglomerate can be followed to the south in an unbroken course along the rock platform on to boulder clay, from the erosion of which it appears to have been in part derived. On the clay the wave-cut shelf becomes less distinct, and the cemented gravels thicken downwards (Fig. 2). The assemblage of stones at Easington, and in the conglomerate to the north and south, is similar to that which is accumulating along the Durham coast at the present day, in places where the cliff is composed of Permian Limestone and boulder clay. (5) The calcreted gravels can be followed in an unbroken course for a considerable distance, and can be traced for some miles. This layer is much more persistent than the platform on which it rests. At several points below the 60-ft. level accumulations of fragmental material occur. These were, in my opinion, formed at the same time as the Raised Beach at Easington. They consist of a series of deposits, varying much in character and coarseness, and are composed of sand, gravel, hard calcreted

conglomerate, and coarse breccia. The gravels are not usually so distinctly bedded, nor do they appear anywhere to contain so many bored rocks and shells as the typical part of the Easington deposit, but that they were formed under the same conditions, and are raised littoral formations, appears clear when the coast between Seaham Harbour and Castle Eden Dene is critically examined. It is important to notice that the top of the level course can be traced along the cliff for a few miles; this layer marks a period of repose in the movements that raised the beaches. It is a most distinct feature and could only have been so uniformly laid down by marginal deposition. The beds vary considerably, but they always contain the same assemblage of local and foreign rocks, and shell fragments can generally be seen in most exposures when they are examined carefully. The series of sections along this coast is, in my opinion,

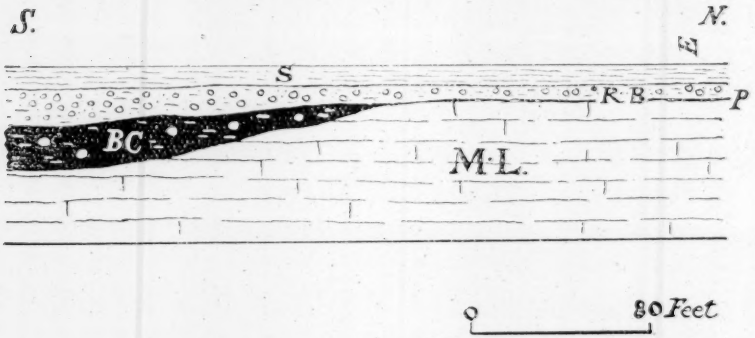

Fig. 2.—Section along the face of the cliff at Easington. M.L. Middle Magnesian Limestone, the eastern equivalents of the Reef. B.C. Main boulder clay with Tweed-Cheviot and Lake District boulders. R.B. Raised Beach resting on rock platform. P. The bedding is most distinct at (but not confined to) the north end, and the platform is less clearly defined when the deposit passes on to clay. S. Deposits of soft shelly sand, brown reassorted boulder clay (Common Clay) rainwash and soil. E. Position of Easington section (Fig. 3). The photographs, Figs. 1 and 2, are also of the cliff at this point.

that which might be expected under the conditions in which a late Pleistocene beach would be formed, and afterwards upraised. It has been suggested that, although the deposit at Easington is undoubtedly a beach, yet the course of cemented gravels on the same level may be of Fluvio-glacial origin; but the mode of occurrence of these beds is unlike that of material of this type of deposition, which has a tendency to occur in mounds, swellings, and irregular beds, and not in extensive regular courses, except where it has been washed into a lake or the sea. It is also impossible to draw any line between what is undoubtedly a beach and that which is conjectured to be Fluvio-glacial. Another point of interest is that in deciding that a deposit is an uplifted littoral formation, we insist

that it shall possess certain well-defined characters, such as the Easington deposit so clearly displays; but it is certain that all these features cannot always be found at every point in such formations. If, for example, the present coast of Durham was uplifted, there are few places at which such a *tout ensemble* of characters as we find at Easington could be seen in the elevated deposits. There are not many stretches of the shore where there are accumulating such a distinctly bedded series of deposits with such an assemblage of shells and bored rocks; in many parts very few bored pebbles and few whole shells occur in the gravels; the shingle is sometimes not distinctly bedded, and often in front of a limestone cliff a coarse, angular deposit is accumulating (which, if uplifted and cemented, would form a breccia similar to that just referred to). Another feature of marginal deposits, which is often not taken into account, is that for a certain distance below high-water mark there is a zone of erosion and most of the shells are either washed up on shore above it or washed out beyond it, so that parts of uplifted strand deposits may contain few or no shells, because they were formed within this zone.

The peculiar mode of occurrence and other features of the sands, gravels, conglomerates, and breccias along the coast of Mid-Durham (together with the definite evidence of Raised Beaches on Fulwell and Cleadon Hills to the north), impressed me when I first studied this coast many years ago, and convinced me that these deposits were marginal sea-deposits. I have collected shell fragments from many parts of these beds, but do not remember collecting any perfect shells [1] (except at Easington), although I was always expecting to find a typical littoral exposure like that at this place. I have no doubt that other similar exposures will be discovered, especially now it is known where to expect them in these deposits. In my opinion the section described in this paper finally settles that these conglomerates are a true Raised Beach, and also proves that they were formed in late Pleistocene times. I further consider that a wave-cut terrace runs along the Durham coast, on which part of these deposits rest. This level platform, with its bed of cemented gravels, forms a noticeable feature of the coast for some miles. It is specially distinct near Easington and Nose's Point, and to the north of Hawthorn Dene. Mr. Lamplugh has asked me to consider the possibility that the beach at Easington may be local (the rest of the course being Fluvio-glacial), and that it is a remnant of a Pre-glacial or early Glacial strand deposit preserved from removal by the ice that swept southwards along this coast,[2] while the rest of the deposit was removed ; [3] while, on the other hand, Dr. Trechmann

[1] I have obtained numerous perfect *Littorinas* from the higher beach on Fulwell, and some have been found in the Cleadon Sand Pit, etc.

[2] "The Interglacial Problem and the Glacial and Post-Glacial sequence in Northumberland and Durham": Geol. Mag., Vol. LVIII, 1921, p. 27.

[3] e.g. the Horsebridge Head deposit near Newbiggen, and the Sewerby Raised Beach near Flamborough Head were so preserved.

has suggested the possibility that it may be the remnant of an Interglacial (or Glaciation-Interval) beach, preserved in a similar way. I am unable to accept either of these hypotheses. The points definitely against them are (1) the fauna is a recent temperate one—there are apparently no species characteristic of Arctic conditions, (2) pebbles of Lake District, Cheviot, and Firth of Forth rocks occur in the deposit, (3) it is not overlaid by true boulder clay but by reassorted boulder clay, (4) it is impossible to isolate the part of of the beds that is allowed by everyone to be a littoral deposit, from that which is conjectured to be Fluvio-glacial, (5) since the top of the course of calcreted gravels is regular and persistent (even if we assume the rest of the beach has been removed by ice) we should have to admit that the Fluvio-glacial beds are forming a kind of pseudomorph of the beach for some miles, and maintaining a uniform level, whether the platform is Magnesian Limestone or boulder clay. It would appear impossible, if the whole of the beach were removed, that the platform of boulder clay would not have been destroyed by the conjectured ice-movement, and highly improbable that the top of the Fluvio-glacial gravels that replaced the beach could always maintain a uniform level for such a long distance.

One of the objections raised some years ago against the occurrence of late-Glacial or Post-glacial Raised Beaches on the Durham coast, was that it had been found impossible to trace them in Yorkshire,[1] and another that there was a considerable stretch of country to the north from which marine deposits of this age are apparently absent.[2] One of the causes of this may be that they are in reality late-glacial and that although the Durham littoral was free from ice when they were forming, yet it was still occupying part of the coast of north-east England, while another is that the uplift was not a uniform one. I further think that the great amount of coastal denudation and reassortment of glacial material along the main rivers that has taken place since the end of the Ice Age is not appreciated by all geologists. From parts of the coast (e.g. north-east Yorkshire) the beaches may have been removed by denudation of the superficial deposits that once covered this coast as with a mantle. It is of interest in connexion with this subject that late Pleistocene raised marine shore-lines passing into river terraces do occur up to about 125 feet in the Firths of Forth, Clyde, Tay, and elsewhere in Scotland,[3] and that an

[1] The estuarine leafy clays and well-worn shingle which occur at Kirmington (Lincolnshire) obviously lessens the force of this argument (see footnote p. 71).

[2] Low level beaches (30 feet (?) and 10 feet) do occur in North Northumberland, and high level beaches (125 feet) occur in Scotland.

[3] In these deposits fossils are scarce, but the shells found in connexion with the higher beds indicate a colder climate than those of the Durham beaches. The fauna includes *Pecten greenlandicus*, *Leda arctica*, *Tellina myopsis* (all Arctic forms) and remains of the small Arctic seal. The lower terrace is associated with clays containing *Scrobicularia piperata* (which also occurs in the Kirmington deposit), and indicates the incoming of warmer conditions. J. Geikie, *Great Ice Age*, p. 273, and *Geol. Surv. Mem.*: "The Neighbourhood of Edinburgh," 1910, p. 335.

estuarine deposit, also of somewhat similar age, has been described from Kirmington, in Lincolnshire, at an elevation of 60–80 feet,[1] and that there are evidences of late Glacial and Post-glacial uplifts in the Wash [2] and West Norfolk [3] and other parts of England.

While the Raised Beach at Easington is in itself of much interest, yet it is, as stated in the beginning of this paper, in connexion with the formation of a considerable part of the upper sands, leafy, stony, stoneless, and prismatic clays that the uplift proved by it (and the higher beach in North Durham) becomes of importance in general Glacial geology. It is clear that much of the material along the east coast of England and up the buried Pre-glacial valleys of the "Tyne" and "Tees",[4] etc.—which has been considered to be true boulder clay is in reality reassorted clay (both stony and stoneless clays), or which has been conjectured to have been deposited in Glacier-lakes (leafy clays), or which has been thought to be of Fluvio-glacial origin (sand and gravel)—is of estuarine and marine origin, and was formed when the coastal region was embayed near the end of the Glacial period. The scarcity of the fossil remains in the clays and sands of estuarine origin may be partly owing to the turbid nature of the waters brought about by the rapid denudation of the Glacial and Fluvio-glacial deposits, and also to the comparatively short period and to the rather rapid nature of the movements during which they were deposited. It seems obvious that after the retreat of the ice-sheet and the incoming of the sea a marine fauna would be able to establish itself much more quickly than an estuarine or freshwater one in the north of England. Tracks of some form of locomotive life are common on some of the layers of the leafy clays, but no shells have been observed by any geologist. Shells and bored pebbles are reported to have been found in some clays in a brickfield near Harton, but Mr. E. Merrick, who has made a detailed study in the field of the clays of the Tyne and Wear districts, has never found any shells in them, although he has verified the occurrence of the bored pebbles. A molluscan estuarine fauna has not yet been proved to have inhabited the Tyne

[1] B.A. Report, Cambridge, 1904, p. 272. In this section there is a deposit of laminated clay with estuarine shells, etc., at about 70–80 feet above sea-level. It is underlaid by Purple Drift (= Main or British Drift of Durham Coast) and above it is a well-worn beach-shingle, principally of battered flints and a clay with foreign stones. Is this clay a true boulder clay? Is it Hessle clay? If so, it is the equivalent of the Durham Prismatic Clay and other reassorted clays which are not of direct Glacial origin. The Kirmington deposit is, in my opinion, late Pleistocene, and may be similar in age to the raised marine deposits of the Durham littoral and contemporaneous with some of the leafy and other clays of the Tyne Valley, etc. The evidence does not appear to be sufficient to prove the Kirmington deposit to be an Interglacial (or even an Interval) deposit, see Lamplugh, "The Interglacial Problem in the British Isles": *International Geological Congress, Canada*, 1913, p. 3.

[2] *Geology in the Field*, p. 175.

[3] Woodward's *Geol. of England and Wales*, p. 555.

[4] e.g. the Brown clay, Common clay, etc., of the Tyne valley.

Valley during the formation of these deposits, but there is clear proof that a fauna of this type existed while the leafy clays (already noticed, p. 70) of a somewhat similar age were being deposited at Kirmington (Lincs.). The mollusca there include *Scrobicularia piperata*, *Cardium edule*, *Mytilus edulis*, *Tellina balthica* (B. A. Report, 1904, p. 273). I do not, however, propose to discuss the extent, thickness, and character of these estuarine deposits in the Tyne-Wear region until the higher Raised Beach has been as definitely proved as the Easington one, and the results of Merrick's study of these deposits published.

There is much evidence which, in my opinion, is quite definite and sufficient, but which might be more fully investigated for the occurrence of late Pleistocene marine and estuarine deposits up to 140–50 feet in north-east Durham, of a slightly later age than the Easington Raised Beach.[1] It includes (1) a cave at Marsden, (2) a cliff with bedded deposits, containing shells and shell fragments resting against it on Fulwell and Cleadon Hills, (3) apparently wave-worn rock surfaces on which the deposits rest, (4) shell-bearing gravels and sands which are distinct from the Kames and Fluvio-glacial gravels and sands, (5) horizontally and current-bedded gravels and sands, (6) ripple-marked sands, and (7) extensive deposits of leafy and other clays. There are several sections in which portions of these deposits are exposed, but it is difficult to get one similar to that at Easington, which would indisputably prove their marine origin. Such sections have been described (as e.g. the exposure in Fulwell Quarries, which I examined during 1900–6), and it is hoped that one will soon be again. A critical examination of the series of exposures which can be seen at the present time would, however, be quite sufficient to settle conclusively that raised marine and estuarine deposits do occur up to 150 feet above sea-level along the Durham coastal region.

Addendum I.—The Permian in the immediate neighbourhood of the Easington deposit is also very interesting. In the railway cutting above there is one of the best fossiliferous exposures of the Bryozoa Reef, which is replaced in the cliff by unfossiliferous bedded rocks and breccias, i.e. by its eastern equivalents (Fig. 1).

Addendum II.—The general sequence of the Pleistocene and Recent deposits along the Durham coastal region is

[1] The higher part of the Easington gravels (90 feet) may be contemporaneous with this 150 beach in north-east Durham. I stated in my paper on "The Superficial Deposits of the Northumberland and Durham Coalfield" (*op. jam. cit.*, p. 75) that the course of cemented gravels of which the Easington deposit forms a part appears to rise very gradually from south to north. This observation, which now that these deposits are proved to be of littoral formation, is one worthy of investigation and surveying, as if it is correct, and due to the uplift only, it should not only be of value in considering the Pleistocene deposits of the East of England, but also in connexion with an important subject in theoretical geology, viz. that such changes of level as the Easington and similar formations prove were due to movements of the terrestrial crust and not to oscillations of the surface of the ocean (Sir A. Geikie, *Q.J.G.S.*, vol. lx, 1904, p. cix).

Soil, Rainwash, Present Beach, and Wind-blown deposits.				Recent
Submerged Forests.	Peat deposits with stumps of trees grown in situ.	Produced by a depression [1] and settling down of the deposits.	Whitburn Bay, Hart'epool.	Neolithic.
Higher Raised Beach (150 feet) (Cleadon and Fulwell Hills). Lower Raised Beach. (60 feet) (Easington).	Prismatic clay. Sand and gravel deposits. Deposition of much reassorted boulder clay [2] (stony clay), leafy clays, and of fine sandy deposits.[3]	Their formation was followed by an uplift. The estuarine and marine deposits laid down while these beaches were being formed are varied and reach a considerable thickness and extent.[4]	Raised Beaches at Marsden, Fulwell, and Easington. Sands and gravels of Cleadon Leafy clays and Stony clays of the Tyne valley, Wash, etc. Sands and gravels along coast, from Sunderland to Ryhope, North of Castle Eden Dene, etc.	Post-Pleistocene passing down into late Pleistocene.
Main or British Boulder Clay.[5]	True boulder clay with Firth of Forth, Tweed-Cheviot, and Lake District erratics.	Moraine profonde of a Piedmont glacier. The British ice was forced southwards along the coast by the ice occupying the North Sea area. The Grindon and Sheraton Kaims were deposited on the free western margin of the Tweed-Cheviot ice during the Retreat phase.	Forms a thick deposit at several places along the Durham coast, Whitburn Bay, Hendon, Warren House Gill, etc.	Pleistocene.
Loess.	Wind-blown glacial mud.	Interval deposit.	Warren House Gill.	Glaciation. Interval.
Durham Basement Clay.[6]	Shelly boulder clay with Scandinavian and North Sea boulders.	Moraine profonde of the Scandinavian and North Sea ice.	Warren House Gill.	Early Pleistocene.

* This table does not include the complicated series of deposits in the Tyne valley. For footnotes see next page.

EXPLANATION OF PLATE V.

FIG. 1.—60-ft. Raised Beach at Easington. The section shown is about 6 feet in thickness and consists of bedded sands and gravels resting on a wave-cut platform of Magnesian Limestone. In a cutting which was made above the deposit the bedded cemented gravels and sands were proved to be 15 feet in thickness (on the face), overlaid by a few inches of loose shell-bearing sand, above which was reassorted boulder clay. The whole being covered by washed soil.

FIG. 2.—Photographs of cliffs at Easington, showing 60-ft. Raised Beach resting on rock shelf. The cliff is about 75 feet high. Along the part shown the beach rests on limestone, but the course of cemented gravels can be distinctly followed to the south, when it passes on to boulder clay. The platform becomes less uniform and distinct and the gravels thicken downwards. The top of the course, however, keeps on the same level. R. Raised Beach. M. Middle Magnesian Limestone—eastern equivalents of the Reef which forms Beacon Hill immediately behind the coast at this point. (Fig. 3.)

The Carboniferous Limestone Series of West Cumberland.

By CHARLES EDMONDS.

INTRODUCTION.

THE area under consideration extends from the mining town of Egremont to Scalesmoor Farm in the parish of Lamplugh in West Cumberland, and comprises a tract of country 9 miles in length and rather less than 3 miles in width, running from S.S.W. to N.N.E. It forms the south-eastern margin of the Whitehaven Coalfield, and is the western portion of the "collar" of Lower Carboniferous rocks almost surrounding the older Palæozoic rocks of which the Lake District proper is composed. The area consists

Notes to p. 73.

[1] Mr. E. Merrick informs me this depression can be definitely proved to have occurred.

[2] Some of the clay with boulders (unstriated or occasionally striated) which is often called boulder-clay is not of direct Glacial origin, but is reassorted material. Another term should be used to distinguish it, perhaps "Stony clay" would do.

[3] This statement is true whether we accept the higher beach as proved or not, although in my opinion the extent and mode of occurrence of the leafy clays necessitate the existence of the higher beach. The formation of the beaches was contemporaneous with the deposition of stony and stoneless reassorted non-laminated clays and with leafy clays; and the uplift with extensive erosion of these and earlier Glacial and Fluvio-glacial beds. The Kirmington estuarine deposit was probably laid down at the same time as the leafy clays of the Tyne valley.

[4] I am of the opinion that the sea invaded the area as the ice was melting. The rafted boulders which have been dropped into the deposits were carried by floating ice (no remains of trees are found in the clays), and the contorted sands that sometimes occur (e.g. Ryhope) were probably produced by stranding ice-blocks.

[5] Same as the Purple Clay of Yorkshire.

[6] The Yorkshire Basement Clay is probably slightly later than the Durham. The evidence appears to prove that there was a Glaciation-Interval (Interglacial Period ?) between.

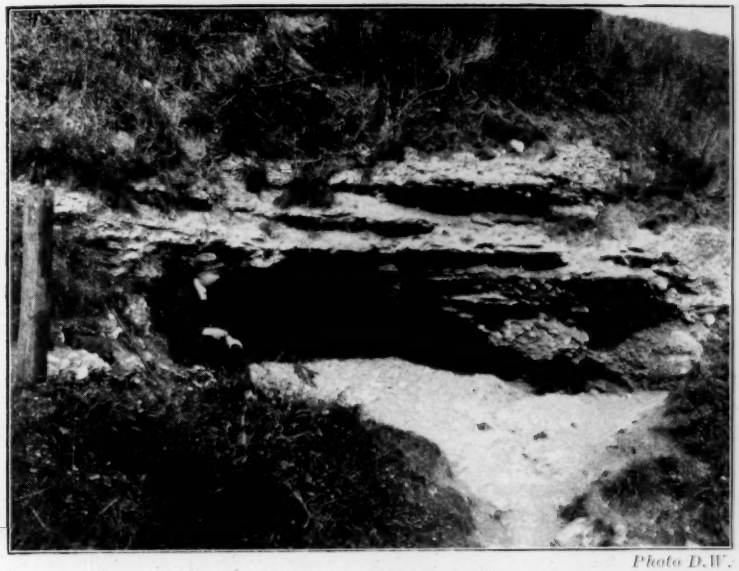

Photo D.W.

FIG. 1.—60 ft. Raised Beach at Easington.

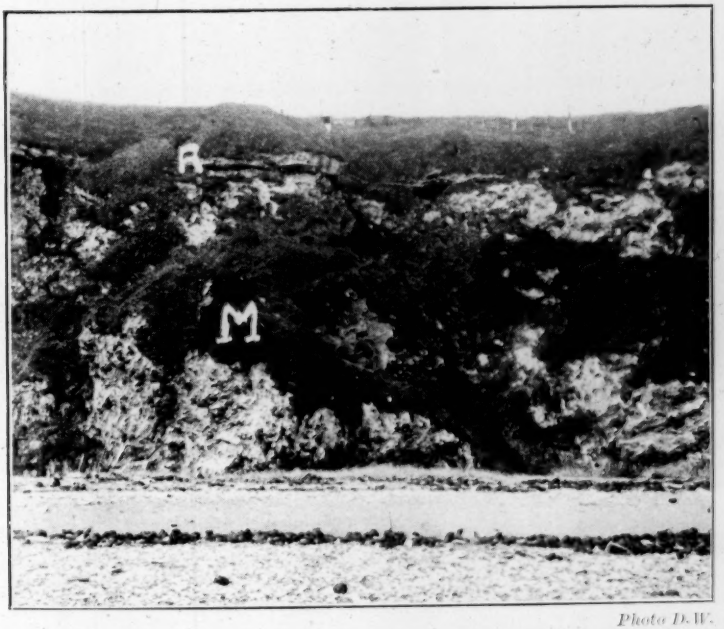

Photo D.W.

FIG. 2.—Photograph of cliff at Easington showing 60 ft. Raised Beach resting on rock shelf.

[*To face p. 74.*

in the main of fairly continuous outcrops, but is much disturbed by faulting. In the unravelling of the tectonics of the district, however, the difficulty caused by excessive faulting is counterbalanced by the multiplicity of the borings that have been made during the exploration and development of the valuable hæmatite deposits associated with the limestones. In no single instance is there an exposure giving a complete section of the sequence, yet with the help of the journals of the "bores" every one of the exposures mentioned in this paper can be placed at its exact horizon with great accuracy.

The area has been mapped by the officers of the Geological Survey.[1] The only memoir dealing with the limestone is that on the hæmatite by B. Smith [2] recently published, in which the names and thicknesses of the various limestones are detailed.

In 1869 W. Brockbank [3] gave some notes on the Aldby Limestone. The horizon is not mentioned, nor are the fossil contents enumerated, which is to be regretted, as this exposure has been covered over with slag heaps. The most important work on the area under consideration is that of Mr. J. D. Kendall.[4] Mr. Kendall describes the succession very minutely, records the general lithological characteristics, gives numerous sections, makes comparisons with sections outside our area, and defines the double system or two systems of faulting. No attempt is made to supply any exhaustive account of lithological details, nor are the fossil contents catalogued with any completeness. Mr. J. G. Goodchild,[5] in a paper on the Limestones of Cumberland and Westmorland, makes mention of our area in pointing out the attenuation of the detrital rocks interbedded with the limestones as our district is approached from the north and north-east. Since then nothing worthy of note has been done, and no attempt at anything like a thorough investigation of the fossil fauna has been made. With the exception of some specimens of *Productus* cf. *giganteus* Mart., one or two other brachiopods, and some very fine specimens of *Lonsdaleia* (all without localities) in the museum of the Whitehaven Scientific Association, there are no public collections of Carboniferous Limestone fossils in the district.

The author began collecting in 1910 with a view to correlating the different beds of the various outcrops; more especially was he anxious to establish definite palæontological horizons in the Egremont portion of the area, where the upper beds with the easily identified Orebank Sandstone are usually denuded, and the interbedded sandstones and shales of the lower portion of the series are not well

[1] Sheet 101 S.W. (New Series, Sheet 28)

[2] Special Reports, vol. viii,—*Iron Ores: Hæmatites of West Cumberland, etc.*, 1919.

[3] *Proc. Manch. Lit. and Phil. Soc.*; GEOL. MAG., Vol. VI, p. 141 (Abstract).

[4] "The Carboniferous Rocks of Cumb. and N. Lanes or Furness": *Trans. N. of Eng. Inst. Min. and Mech. Eng.*, vol. xxxiv, 1885, p. 185.

[5] "Notes on some of the Limestones of Cumb. and Westm.": *Trans. Cumb. and Westm. Assoc.*, No. xvi, 1890–1, p. 134.

defined. It was thought that if such horizons could be definitely established and readily recognized they might be of economic advantage in the location and exploitation of the ore-bodies in that part of the district. The results obtained then and since afford a basis for a comparison with the faunal divisions established elsewhere by the classic work of Vaughan [1] and Garwood [2]; whilst the lithological examination reveals certain interesting rock-types which are also prevalent in other areas, especially many of those described by Mr. E. E. L. Dixon [3] in his work on Gower.

The following pages are intended to be a preliminary account of the full work.

General Structural and Physical Features of the Outcrops.

At Egremont, the southern extremity of the outcrop of the Carboniferous Limestone of West Cumberland, the various members of the series emerge from beneath a covering of New Red rocks, viz. the St. Bees Sandstone, red marls, and breccia. The Fourth or Clints Limestone (Table II), the thickest member of the series, appears at the surface on the north-west side of the town in Gillfoot Park and forms the high ground on the west side of the Egremont-Whitehaven road, and then as a marked ridge passes through Clints to Woodend Station. West of this ridge the First or Bigrigg Limestone crops out near Langhorn Farm; it is then shifted to the east behind Bigrigg Moor houses, where it is thrown down by various faults and does not re-emerge until Birks Farm, north-east of Cleator Moor, is reached. The bottom beds, the Sixth and Seventh Limestones, form the bed of the Ehen River for a short distance north-east of Briscoe Mount. The Seventh or Bottom Limestone reappearing at Todholes, is the outcrop limestone as far as Frizington Parks, where the series is shifted to the east by the great Yeathouse fault, which brings the St. Bees Sandstone down to the same level as the Bottom Limestone. The Fourth Limestone can again be traced by a marked ridge east of Frizington, and again at Eskett, Salter, and Rowrah. From Kelton Head Quarries it passes through Lamplugh to Scalesmoor Farm.

The Orebank Sandstone, a more or less shaly sandstone lying between the Second and Third Limestones, can usually be traced as a level tract between the higher ridge caused by the thick Third and Fourth Limestones and the lesser ridge formed by the First and Second Limestones, in spite of the fact that the contour of the district has been considerably modified by glacial agencies and recent denudation. On the whole, the outcrop of the series presents an alternation of terrace scarps and more level tracts, the gentle

[1] "The Palæontological Sequence in the Carboniferous Limestone of the Bristol Area": *Q.J.G.S.*, vol. lxi, 1905, p. 181.

[2] "On the Lower Carboniferous Succession in the North-West of England": *Q.J.G.S.*, vol. lxviii, 1912, p. 449.

[3] "The Carboniferous Succession in Gower": *Q.J.G.S.*, vol. lxvii, 1911, p. 477.

slopes coinciding with the dip of the strata, which is usually to the west or south-west.

The drainage of the area is for the most part post-glacial, the Rivers Keekle and Ehen crossing or running along the sides of faults indiscriminately. Two outcrops appear outside the tract of country mentioned. One is at Overend, 1½ miles south-east of Whitehaven, where the First, Second, and Third Limestones have been pushed up through the Millstone Grit and Coal Measures; and the other is at Wilton, a mile east of Egremont, where the Seventh Limestone, isolated amid Lower Palæozoics, has been saved from denudation by slight synclinal folding. The Whitehaven Millstone Grit and Coal Measures border the limestone tract on its western side for the greater portion of its length.

The Carboniferous Limestone Series and Millstone Grit of W. Cumberland.

Table I.—Lithology.

		Thickness. S.W. ft.	N.E. ft.
Millstone Grit	Coarse grits with quartz-pebbles and felspar-fragments. Sandy, mottled, and finely laminated black shales, fossiliferous. Thin coal, 4 in. 0	60	120
First Limestone	Dark blue-grey limestone: towards top thinly bedded with sinuous but persistent bedding-planes; lower portion massive. Occasional small veins of barytes	40	60
First Shale	Thinly laminated shale with thin coal and sandstone	12	14
Second Limestone	Dark blue-grey limestone, thick-bedded	14	24
Orebank Sandstone	Fine-grained micaceous sandstones with one or two coarser bands; becomes largely dark shales in N.E.	40	70
Third Limestone	Reddish-grey crinoidal limestone	12	15
Third Shale	Mottled shale, sandy and micaceous	6	8
Fourth Limestone	(For sub-divisions and characters see Table III.)	256	312
Fourth Shale	Green shales, sandy mudstones, and micaceous sandstone	14	24
Fifth Limestone	Upper portion (A) white or reddish-grey limestone usually much jointed; separated from dark blue-grey lower portion (B) by thin mudstone. Pseudo-breccias in (B)	50	70
Sandstone and Shale	Upper portion thinly bedded sandstone, with finely laminated black fossiliferous shale in lower portion	14	24
Sixth Limestone	Blue-grey limestone, thick-bedded, with pseudo-breccias, much divided in places by black shales of variable thicknesses	54	70
Thin Beds	Nodular limestone with thinly bedded limestones, shales, mudstones, and calcite-mudstones	10	20

		Thickness. S.W.	N.E.
Seventh Limestone	Evenly-bedded grey limestones with diagonally-bedded sandstones near base and summit; chinastone-limestone and pseudo-pisolite; chert nodules at one or two levels. Dolomite-mudstones and calcite-mudstones with black shales at base	ft. 60	ft. 160
Basement Bed	Dark-grey shale, sandy, and conglomeratic in parts, with small comminuted quartz-pebbles throughout.	3	6

TABLE II.—PALÆONTOLOGY.

Millstone Grit	Coarse grits and sandstones contain plant-impressions. Black shales contain Goniatites in abundance, *Pterinopecten sp.*, *Lingula sp.*, and many gastropods.
First Limestone	*Productus giganteus* Mart., *P. latissimus* J. Sow., *Schellwienella crenistria* (Phill.), *Athyris planosulcata* (Phill.), and *Orbiculoidea nitida* Phill. are the chief brachiopods. Corals abundant: *Dibunophyllum muirheadi* Thom., *Aulophyllum fungites pachyendothecum* Thom. em. S. Smith, *Koninckophyllum magnificum* Thom., *Caninia* cf. *sub-ibicina* McCoy, and *Lonsdaleia floriformis* (Mart.) mut. *laticlavia* S. Smith are chief forms.
First Shale	Plant-impressions and indeterminable casts of lamellibranchs.
Second Limestone	*Productus latissimus* J. Sow., *P. semircticulatus* Mart., *Dibunophyllum sp.*, *Zaphrentis* cf. *disjuncta* Thom.
Orebank Sandstone	Plant-impressions in many bands.
Third Limestone	Fauna sparse, *Zaphrentis enniskilleni* Edw. & H. and *Diphyphyllum lateseptatum* McCoy are chief corals.
Third Shale	No fossils.
Fourth Limestone	(For palæontology of Fourth Limestone see Table IV.)
Fourth Shale	No fossils.
Fifth Limestone	*Productus* cf. *maximus* McCoy, *P. semircticulatus* Mart., *P. cora* d'Orb. mut. D_1, *Chonetes papilionacea* (Phill.) are characteristic and abundant brachiopods. Coral fauna contains a maximum of *Cyathophyllum murchisoni* Edw. & H., *Koninckophyllum sp.*, *Carcinophyllum sp.*, *Dibunophyllum* θ Vaughan, with *Lonsdaleia duplicata* (Mart.) mut. *melmerbiensis* S. Smith highly characteristic.
Sandstone and Shale	Sandstone contains worm-tracks, rain-prints, etc. Black shale is crowded with *Chonetes hardrensis* (Phill.), *Leptæna analoga* Phill., *Productus longispinus* Dav., and many lamellibranchs.
Sixth Limestone	*Productus maximus* McCoy, *Chonetes* aff. *papilionacea* (Phill.), *Dibunophyllum* θ Vaughan (rare), *Carcinophyllum* θ Vaughan, *Lithostrotion martini* Edw. & H. characteristic and abundant.
Thin Beds	Nodular bed probably algal. *Spiriferina* cf. *laminosa* McCoy abundant. *Pugnax pugnus* Mart. and *Seminula ficoidea* Vaughan. Fish teeth fairly common. Calcite-mudstones contain *Spirorbis*-

	like annelids, small gastropods, *Calcisphæra*. Shales contain lamellibranchs, *Aviculopecten* cf. *plano-clathratus* McCoy and *Modiola sp.*
Seventh Limestone .	*Productus maximus* McCoy, *P. cora* d'Orb. mut. S_2, *P. corrugato-hemisphericus* Vaughan abundant and characteristic. *P. scabriculus* Mart., *Dielasma* cf. *sacculus* (Mart.), *Seminula* cf. *ficoidea* Vaughan, *Cyrtina sp.*, *Cyathophyllum* cf. *ϕ* Vaughan, *Nematophyllum minus* McCoy, *Carcinophyllum sp.* near *θ* Vaughan, *Caninia* cf. *patula* Mich. *Syringopora* sp. [a distinct form].
Basement Beds . .	Plant impressions and casts of *Productus*.

General Lithological Description of the Series.

The series consists of a number of massive to thinly bedded limestones interspersed with beds of sandstone, shale, or mudstone (see Tables I and III).

The limestones are most commonly of standard type, viz. with a standard marine fauna. Their texture ranges from coarse granular crinoidal rocks to very fine-grained or porcellanous "calcite-mudstones",[1] which include "chinastone-limestones". In colour they vary from white through reddish-grey and blue to almost black, beds on the same horizon differing according to the presence or absence of hæmatite in the vicinity.

The shales and mudstones range in colour from pale green or grey through reddish-grey to purple and black; in thickness from paper-thin partings to beds 12 to 14 feet in thickness. The mudstones associated with the Fourth Limestones are mottled (white, red, and purple), and are either purely argillaceous (weathering to a crumbly clay) or sandy-argillaceous; they are known in the district and are recorded on the Vertical Sections published by the Geological Survey as mottled shales. The shales in the upper limestones are carbonaceous. Mica is usually present in the sandy shales, but is absent from the mudstones. The sandstones intercalated between the limestones are generally stained red and purple, and, with the exception of one or two coarser bands in the Orebank Sandstone, are mainly fine-grained. Mica is usually present. No limestone exactly like the Bryozoa Bed (Hor. *a*) of Bristol is present, but rocks somewhat resembling it occur near the base and summit of the Seventh or Bottom Limestone and again near the top of the Fourth Limestone. A rock suggesting the "Seminula Pisolite" of the Avon Section occurs near the summit of the Seventh Limestone.

Subsequent dolomitization occurs locally in many of the limestones; it is frequently associated with hæmatite. Dolomite-mudstones are common at the base of the series, but no contemporaneous dolomitization has been observed. A fine-grained calcite-mudstone, about 2 feet thick, weathering white and fracturing conchoidally, like the "chinastones" of the S.W. Province, occurs midway in the Seventh Limestone, whilst other calcite-mudstones,

[1] The terms "calcite-mudstones" and "dolomite-mudstones" are used for rock-types similar to those described by Mr. Dixon (*op. cit.*, pp. 516–17).

with ostracods, small gastropods, and *Spirorbis*-like annelids, occur at two or three horizons. Purely crinoid limestone, suggestive of "petit-granite", occurs rarely (one or two bands), but crinoid-ossicles are abundant in most of the limestones. Foraminiferal limestones are almost universal, but foraminifera are specially abundant and attain considerable dimensions in the "Spotted Beds" near the middle of the Fourth Limestone. *Saccammina* characterizes a particular horizon of this limestone throughout the area. Limestones that are more or less definitely algal [1] occur at three or four separate levels. *Girvanella sp.* is abundant in a particular band of the Fourth Limestone throughout the district, and the white limestones immediately below are particularly rich in what appear to be algal remains.

Iron pyrites occurs in the Second Limestone at Overend, and is often abundant in the shales, being remarkably ubiquitous in the shaly Basement Conglomerate. Small veins of barytes occur in the First Limestone at Langhorn, and in many of the beds at Kelton Head; it is often associated with hæmatite. Hæmatite is found in variously formed masses and irrespective of any particular horizon, but whilst it has been found in all the limestones an analysis of the occurrences proves that there are three horizons where hæmatite deposits are more general than at other levels. The first is at the base of the First Limestone, the second rests on what is known locally as the Fourth Shale (the shale at the base of the Fourth Limestone), and the third lies on the Basement Shale. Crystals of calcite are abundant throughout West Cumberland having supplied many specimens to museums all over Europe. Fluorspar is found more sparingly. "Pseudobreccias," similar to those described by Dixon and Garwood from the D Zone of the South-West and North-West Provinces, are present at many levels, and are well developed in the Fourth Limestone; "spotted beds" are confined to that level. Chert occurs in nodules near the base and towards the top of the Seventh Limestone, and sparingly along the bedding at the top of the Fourth Limestone. Some of the nodules show concentric zoning. Beekite and other forms of silica replace corals and brachiopods in some beds.

Diagonally Bedded Sands.—A feature to be noticed occurs in the Seventh Limestone at two distinct horizons, one about 20 feet above the Basement Conglomerate and the other at the top of the limestone. Grains of red and brown quartz enter the limestone in "diagonal" (cross) bedding, forming diamond-shaped "frames" that enclose masses of almost purely crinoidal limestone. *Spirifer*, *Dielasma*, *Seminula* cf. *ambigua*, and other brachiopods persist upwards through the sands, and are preserved as casts in the sandstone itself. The lower of the sandy episodes consists of bands of a few inches thickness, whilst the one at the top of the Seventh

[1] Attention has been drawn by Garwood and Reynolds to the importance of algæ as rock builders of Carboniferous and other limestones.

Limestone developes in places into a sandstone, 6 to 10 feet thick, with numerous plant-impressions. On a weathered surface the sand-grains stand out as brown lines, and give the rock a striking appearance. The walls on either side of the Rowrah to Kirkland road are built of this limestone and show up the diagonal bedding to perfection. This feature, when present, distinguishes the Seventh or Bottom Limestone, being absent from all the other limestones.

The Fourth Limestone.—The Fourth Limestone (Tab. III) can be subdivided into several distinct beds, and the intercalated mudstones, shales, and sandstones are persistent over an area extending beyond the limits of the district under consideration. This limestone, which is highly fossiliferous throughout its thickness, affords the best exposures throughout the district, and is the one most frequently quarried; indeed, at present (1921) no quarry is being worked in any other limestone. The thicknesses usually given in vertical sections are 256 feet in the vicinity of Clints and 312 feet at Yeathouse, but by direct measurement the thicknesses are slightly less. The best exposures are at Kelton Head and Rowrah Head, where the full sequence can be seen and studied. Other good exposures, but lacking some of the top beds and their connexion with the Third Limestone, are at Rowrah Hall, Salter Hall, Postlethwaite's Eskett, Yeathouse, and Clints Quarries. The junction of the D_1- with the D_2-subzone occurs about 50 feet above the base of this limestone; it is distinguished by a thin calcite-mudstone lying between shales with plant-impressions. The calcite-mudstone contains *Spirorbis*-like annelids, small gastropods, beside *Girvanella sp.* and similar algæ. *Girvanella sp.* also occurs encrusting small fossils and crinoid-fragments in the limestone immediately above the calcite-mudstone.

THE FOURTH LIMESTONE.

TABLE III.—LITHOLOGY.

		Thickness. S.W. ft.	N.E. ft.
Black Chert Beds	Dark blue-grey limestone with chert nodules along bedding; middle bed calcite-mudstone	10	15
Shale	Mottled mudstone, with concretions	1	2
Junceum Beds	Thick-bedded blue-grey limestone with platy crinoidal band towards top. Chert (Kelton Head). Little shale along bedding planes which are usually concretionary towards top but absent in massive lower portion	55	65
Saccammina Beds	Greenish-grey limestone separated from above by 1–2 feet of mottled shale or mudstone	18	25
Upper Algal (?) Band.	Micaceous sandstone (Clints); nodular and porcellanous limestone	2	5
Pot-holes Bed	Thick post of light-grey limestone without shale partings. Pot-holes abundant and persistent.	6	

		Thickness. S.W. ft.	N.E. ft.
	"Spotted," the "spots" being large patches of pink staining on light-grey matrix. . . .	20	30
Shale, mudstone, or sandstone.	Shale and mudstone (Clints); sandstone (Frizington) . . .	2	3
Spotted Beds . .	Thickly-bedded light-grey limestone with two or three thin shales or mudstones; "spots" mainly dark-grey ("matrix" light-grey), more or less circular in one or two bands, about 1 in. in diam. in lower portion, increasing upwards . .	30	35
Thin Mudstone . .			
Rough Beds . .	Dark-grey limestone with pseudo-breccia structure and "wavy" bedding planes; highly bituminous towards base	50	60
Shale . . .	Shale, mudstone, and calcite-mudstone	1	2
White Beds . .	White limestones in 5 or 6 beds with 3 or 4 mottled mudstones 1–10 feet thick. Middle beds much worn by contemporaneous channelling; true limestone-breccias in the mudstones; lower beds faintly spotted. Persistent evenly-bedded limestone-breccia at base	55	65

THE FOURTH LIMESTONE.

TABLE IV.—PALÆONTOLOGY.

Black Chert Beds .	*Productus semireticulatus* Mart., *P. latissimus* J. Sow. *Athyris planosulcata* (Phill.), chief brachiopods. Corals not abundant; *Aulophyllum pachyendothecum* Thom., *Syringopora reticulata* Goldf., with *Chætetes depressus* in wide-spreading flat sheets.
Junceum Beds . .	Fauna particularly abundant; some of the chief forms: *Productus giganteus* Mart. in a distinct band near top of this bed, *P. concinnus* J. Sow., *P. scabriculus* Mart., *P. fimbriatus* J. de C. Sow. *Martinia glabra* (Mart.), *M. ovalis* (Phill.), *Spirifer grandicostatus* McCoy are common. *Lithostrotion junceum* (Flem.) in many distinct bands with *L. portlocki* (Bronn) and *L. maccoyanum* Edw. & H., *Lonsdaleia duplicata* (Mart.) mut. *alstonensis* S. Smith, *Cyathophyllum regium* Phill., *Michelinia tenuisepta* (Phill.), *Dibunophyllum splendens* Thom., *Clisiophyllum* cf. *keyserlingi* McCoy, *Aulophyllum fungites* (Flem.) mut. *cambriense* S. Smith, *Heterophyllum Lyelli* Duncan, and a large form of *Diphyphyllum sp.* are not found in any of the other beds. *Saccammina carteri* Brady occurs at base.
Thin Mudstone . .	Is crowded with *Saccamminæ* at Clints.
Saccammina Beds .	Standard D_2-fauna but macroscopic fossils not abundant. *Saccammina-carteri* Brady [throughout], but most plentiful in a band midway in the beds. *Orionastræa casifer* S. Smith only from here.

Upper Algal (?) Band.	Algæ (?) (Frizington); plants in the sandstone.
Pot-holes Bed . .	Standard fauna, D_2 corals abundant; *Saccammina* in upper beds.
Mudstone . . .	Mudstone unfossiliferous; plants in sandstone.
Spotted Beds . .	Brachiopods particularly abundant in top beds; foraminifera abundant, large *Textularia sp.* characteristic. *Lonsdaleia sp.* [var. in which many septa reach theca]. *Lithostrotion irregulare* Phill. abundant.
Thin Mudstone . .	No fossils.
Rough Beds . .	Typical D_2-fauna abundant, with many lamellibranchs in lower portion. *Chonetes* cf. *comoides* occurs in band near base, and *Girvanella sp.* occurs encrusting crinoid stems and coral fragments in a band at the base and is found in the calcite-mudstone immediately below. Chief associated forms are: *Productus edelburgensis* Phill., *P. maximus* McCoy, *Chonetes compressa* Sibly, *Pugnax pleurodon* (Phill.), *Spirifer bisulcatus* J. de C. Sow., *Dibunophyllum* θ Vaughan, *Caninia denticulata* Thom., *Lonsdaleia floriformis* (Mart.) mut. *crassiconus* S. Smith, *Carcinophyllum sp.*, *Zaphrentis sp.*, *Cyathophyllum murchisoni* Edw. & H., and *Lithostrotion irregulare* Phill.
Calcite Mudstone .	*Spirorbis*-like annelids, *Girvanella sp.*, and many small gastropods.
White Beds . .	Brachiopods abundant in upper beds; *Productus cora* d'Orb. mut. D_1, *P. hemisphericus* J. Sow., *Schizophoria resupinata* (Mart.), *Cyrtina septosa* (?) Phill. A gastropod, *Straparollus acutus* (Sby.), is common. Corals abundant, especially in lower beds, and typical of D_1: *Cyathophyllum murchisoni* Edw. & H., *Carcinophyllum* θ Vaughan, *Dibunophyllum* θ Vaughan, *Caninia* cf. *derbiensis* Vaughan, *Lonsdaleia duplicata* (Mart.), and a Clisiophylloid *Lithostrotion*.

(*To be continued.*)

The Petrology of the Pennant Series, East of the River Taff.

By A. Heard, M.Sc., F.G.S., University College of South Wales and Monmouthshire.

ALTHOUGH much geological research has been done on the Coal Measures of South Wales, little detailed work on the petrology of the series, east of the River Taff, has been published. This work has been undertaken in the hope that the petrology of the district may give a foundation for a reliable correlation or may give a clearer conception of the conditions of deposition and the source of the sediments than is obtained from a study of the coal-seams alone.

The Coal Measures of South Wales are divided into three main groups: the Lower Coal Series, the Pennant Sandstone, and the Upper Coal Series. The upper boundary of the massive sandstone series known as the Pennant Grit, is defined by the Mynyddislwyn

		Thickness. S.W. ft.	N.E. ft.
	"Spotted," the "spots" being large patches of pink staining on light-grey matrix. . . .	20	30
Shale, mudstone, or sandstone.	Shale and mudstone (Clints); sandstone (Frizington) . . .	2	3
Spotted Beds . .	Thickly-bedded light-grey limestone with two or three thin shales or mudstones; "spots" mainly dark-grey ("matrix" light-grey), more of less circular in one or two bands, about 1 in. in diam. in lower portion, increasing upwards . .	30	35
Thin Mudstone . .			
Rough Beds . .	Dark-grey limestone with pseudo-breccia structure and "wavy" bedding planes; highly bituminous towards base	50	60
Shale . . .	Shale, mudstone, and calcite-mudstone	1	2
White Beds . .	White limestones in 5 or 6 beds with 3 or 4 mottled mudstones 1–10 feet thick. Middle beds much worn by contemporaneous channelling; true limestone-breccias in the mudstones; lower beds faintly spotted. Persistent evenly-bedded limestone-breccia at base	55	65

THE FOURTH LIMESTONE.

TABLE IV.—PALÆONTOLOGY.

Black Chert Beds .	*Productus semireticulatus* Mart., *P. latissimus* J. Sow. *Athyris planosulcata* (Phill.), chief brachiopods. Corals not abundant; *Aulophyllum pachyendothecum* Thom., *Syringopora reticulata* Goldf., with *Chaetetes depressus* in wide-spreading flat sheets.
Junceum Beds . .	Fauna particularly abundant; some of the chief forms: *Productus giganteus* Mart. in a distinct band near top of this bed, *P. concinnus* J. Sow., *P. scabriculus* Mart., *P. fimbriatus* J. de C. Sow. *Martinia glabra* (Mart.), *M. ovalis* (Phill.), *Spirifer grandicostatus* McCoy are common. *Lithostrotion junceum* (Flem.) in many distinct bands with *L. portlocki* (Bronn) and *L. maccoyanum* Edw. & H., *Lonsdaleia duplicata* (Mart.) mut. *alstonensis* S. Smith, *Cyathophyllum regium* Phill., *Michelinia tenuisepta* (Phill.), *Dibunophyllum splendens* Thom., *Clisiophyllum* cf. *keyserlingi* McCoy, *Aulophyllum fungites* (Flem.) mut. *cambriense* S. Smith, *Heterophyllum Lyelli* Duncan, and a large form of *Diphyphyllum sp.* are not found in any of the other beds. *Saccammina carteri* Brady occurs at base.
Thin Mudstone . .	Is crowded with *Saccammina* at Clints.
Saccammina Beds .	Standard D_2-fauna but macroscopic fossils not abundant. *Saccammina carteri* Brady [throughout], but most plentiful in a band midway in the beds. *Orionastræa casifer* S. Smith only from here.

Upper Algal (?) Band.	Algæ (?) (Frizington); plants in the sandstone.
Pot-holes Bed . .	Standard fauna, D_2 corals abundant; *Saccammina* in upper beds.
Mudstone . . .	Mudstone unfossiliferous; plants in sandstone.
Spotted Beds . .	Brachiopods particularly abundant in top beds; foraminifera abundant, large *Textularia sp.* characteristic. *Lonsdaleia sp.* [var. in which many septa reach theca]. *Lithostrotion irregulare* Phill. abundant.
Thin Mudstone . .	No fossils.
Rough Beds . .	Typical D_2-fauna abundant, with many lamellibranchs in lower portion. *Chonetes* cf. *comoides* occurs in band near base, and *Girvanella sp.* occurs encrusting crinoid stems and coral fragments in a band at the base and is found in the calcite-mudstone immediately below. Chief associated forms are: *Productus edelburgensis* Phill., *P. maximus* McCoy, *Chonetes compressa* Sibly, *Pugnax pleurodon* (Phill.), *Spirifer bisulcatus* J. de C. Sow., *Dibunophyllum* θ Vaughan, *Caninia denticulata* Thom., *Lonsdaleia floriformis* (Mart.) mut. *crassiconus* S. Smith, *Carcinophyllum sp.*, *Zaphrentis sp.*, *Cyathophyllum murchisoni* Edw. & H., and *Lithostrotion irregulare* Phill.
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(*To be continued.*)

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ALTHOUGH much geological research has been done on the Coal Measures of South Wales, little detailed work on the petrology of the series, east of the River Taff, has been published. This work has been undertaken in the hope that the petrology of the district may give a foundation for a reliable correlation or may give a clearer conception of the conditions of deposition and the source of the sediments than is obtained from a study of the coal-seams alone.

The Coal Measures of South Wales are divided into three main groups: the Lower Coal Series, the Pennant Sandstone, and the Upper Coal Series. The upper boundary of the massive sandstone series known as the Pennant Grit, is defined by the Mynyddislwyn

coal seam of Monmouthshire, and the lower boundary by the No. 2 Rhondda coal seam.[1]

This petrological investigation is chiefly concerned with the Pennants, east of the River Taff, but has been extended to certain areas, such as Garth Hill, west of the Taff. The rock-specimens examined have been selected from various horizons at different localities along the south crop of the coalfield, and from districts as far north as Ferndale, in the Rhondda Valley.

Immediately below the No. 2 Rhondda is a mass of sandstone which so closely resembles the Pennants that it is impossible to distinguish between the two in hand-specimens. These sandstones from the upper part of the Lower Coal Series have been included in the work for the purpose of establishing a relation between them and the Pennants.

Macroscopically, the Pennants may be described as compact micaceous sandstones and flags. The colour in unweathered specimens varies from grey to green, and is sometimes almost black where there is a local concentration of carbonaceous material. Frequently the rock is highly false-bedded, and small lenticular coal-seams appear at many horizons, consisting of material which is clearly detrital matter. Often the sandstones are massive, without any concentration of coal, but in this massive rock silicified plant remains have been found, including numerous large Calamites. Bands of conglomerate and shales are exposed at certain horizons and near the Taff thin sulphury coal-seams appear.

Appearance in Thin Section.

A large number of specimens of Pennant Sandstone, from many different localities, have been sliced and examined. There is little variation shown in the different thin sections. Under the microscope the rock is seen to be a fairly even-grained sandstone, consisting mainly of quartz grains set in a matrix, which is difficult to determine microscopically. Generally an aggregate polarization is shown. Secondly, white mica and quartz are the only minerals which can be identified in the matrix. The secondary quartz is occasionally found enveloping the original quartz grains.

On the whole there is considerable uniformity in the size of the quartz grains, the average diameter being about ·3 mm. in the normal sandstone. These grains are subangular, but tend to become angular with a diminution in size. Much of this angularity is probably due to a secondary deposition of silica. The quartz is clear and remarkably free from inclusions. Undulose extinction is rare in the smaller grains, although in the larger grains it is occasionally visible. Chert is common throughout the series, its brown or yellow colour and its cryptocrystalline structure affording a ready means of recognition. Detrital colourless mica is very

[1] A. Strahan in "The Country around Newport": *Mem. Geol. Surv.* 1909, p. 28.

abundant, in frayed and twisted laths. The felspars are so altered that their exact species cannot be determined with certainty. Dark mica is present in the form of a few frayed laths, which show but little trace of alteration. Chlorite is abundant at every horizon. Black opaque material is common and appears to be mostly carbonaceous matter. Subangular fragments of shale are found scattered throughout the series. Corundum has been detected in a few slides.

The Heavy Minerals.

Specimens of the Pennant Sandstone from numerous localities were crushed but not ground in a mortar, and were subsequently placed upon a series of sieves of mesh 30, 60, 90 to the inch, and well shaken. Most of the heavy minerals passed the 90 mesh, especially the zircon and rutile grains.

The fine dust was removed by careful washing. The pounded rock was not treated with hydrochloric acid before the heavy liquid separation, as this destroyed many of the minerals. The crushed rock was treated with heavy solutions in order to isolate groups of minerals of known density.

The following heavy solutions were used :—

Sonstadt Solution,	Specific	Gravity	= 2·6
Bromoform,	,,	,,	= 2·9
Sonstadt Solution,	,,	,,	= 3·16
Mercurous Nitrate	,,	,,	= 4·3

The bar-magnet and an electro-magnet with adjustable pole-pieces were also utilized, and, after a little experience, it was seldom found necessary to employ a heavy liquid with a S.G. greater than 2·9, except for the purpose of confirmatory tests. The use of simple micro-chemical tests proved valuable in confirming the presence of certain minerals.

The grains, which were isolated by means of hand-picking under a lens, were mounted either in clove oil (Refractive Index = 1·53) or Canada Balsam for microscopic investigation.

The following minerals were separated :—

Siderite.—Moderately magnetic grains with S.G. greater than 3·16. These appeared yellowish in reflected light, and had a high refractive index. Many of the grains were granular and contained particles of carbonaceous matter. In warm hydrochloric acid these fragments gave off an evolution of gas (CO_2), and generally a minute particle of angular silica was left behind after all action had ceased. Much iron was found in the solution on testing. These grains appeared to be free from calcite when the alum test was applied.[1]

Sphærosiderite.—Numerous almost perfectly rounded grains have been placed in this group, distinct from that of siderite, on account of their characteristic form. These bodies were drawn from separation of density greater than 3·18 and less than 4·3 by means

[1] Weinschenk (Clark), *Petrog. Methods*, 1912, p. 151.

of an electro-magnet; they had an average diameter of about 0·1 mm., and were soluble in hydrochloric acid. No nucleus of quartz was observed after all action had ceased. When viewed under the microscope in convergent light and between crossed nicols, beautiful concentric and spherulitic structures were presented; these bodies show the black cross characteristic of radiate aggregates. Other carbonates may have been present in isomorphous intergrowth with the iron carbonate, but neither calcium nor magnesium was detected by chemical tests.

Cordierite.—Fairly fresh grains of this mineral were not abundant, although some samples were found in practically every horizon examined. The grains were irregular, but a few showed traces of a short prismatic habit. The colourless crystals were easily distinguished from quartz by means of their characteristic inclusions of zircon and magnetite. Even the freshest grains showed the beginning of an alteration to a greenish chloritic substance at the edges or near the inclusions. The crystals were drawn out of a crop of density greater than 2·9 by the electro-magnet. This slightly magnetic character was probably due to the inclusions of magnetite, which with those of zircon probably caused the density to be greater than that of normal cordierite.

Zircon was abundant in all horizons of the Pennants, occurring in well-developed prismatic grains of an average size 0·15 by 0·05 mm. Some of the crystals presented an almost perfect form, giving an angle of approximately 48 degrees between prism and pyramid. Many grains were slightly clouded, and showed a zonal structure, a few of these were reddish and slightly magnetic, and may have been xenotime.

Rutile.—This mineral was present throughout the series in subordinate quantities. It generally occurs in the form of rounded yellow or brownish-red grains, although colourless rutile has been detected. Occasionally heart-shaped and geniculate twins were observed. Rutile needles were found in the clays and shales, but not in the sandstones. Its extremely high refractive index, its density, and its sub-metallic lustre, enabled this mineral to be easily detected. A few of the red grains were slightly magnetic, and were probably ferriferous.

Muscovite was separated with difficulty by means of heavy solutions, on account of the large surface area of the cleavage flakes, which caused it to be distributed in all the crops. It was easily separated by rolling the flakes down a rough paper tube, when the mica cleavage flakes remained on the rough paper. Most of the fragments showed some trace of hexagonal structure, and were either dark or gave low interference colours between crossed nicols. Inclusions were frequently present. The secondary mica was in the form of dense scaly aggregates.

Pyrrhotite was found in relatively large quantities at almost every horizon. The grains were irregular, and varied in colour from

a tarnished brown to black. The mineral was picked out by means of a hand magnet, and was decomposed in hydrochloric acid with an evolution of gas.

Chlorite occurred as green scaly aggregates, and also as well-defined green pleochroic cleavage-flakes. This was one of the most abundant of the heavy minerals.

Fluorite has only been observed in one separation from the middle of the Pennants in the South Crop, south of Caerphilly, in the form of triangular cleavage flakes, resulting from the octahedral cleavage. These flakes were colourless and isotropic, and had a refractive index less than that of Canada Balsam.

Corundum was detected occasionally in the crops of the minerals from the sandstones, but a much larger proportion exists in the shales. It occurs as beautiful patchy royal-blue crystals with a very high refractive index and low polarization colours. These crystals appear to have a prismatic form, with cross striations.

Pyrites occurred in irregular nodules, with a bronze-yellow colour in reflected light; these nodules were insoluble in hydrochloric acid, but soluble in nitric acid.

Biotite.—A few thin plates of this mineral have been observed, varying in colour from a dark brown to black. These flakes were drawn from a crop of density greater than 2·9 and less than 3·16 by means of the electro-magnet.

Glauconite.—A few slightly magnetic grains of density less than 2·6 have been referred to this mineral.

Tourmaline in yellowish-brown grains is fairly common. There is a marked pleochroism in these brown grains. Frequently these grains appear as worn, elongated prisms with a high birefringence.

A few grains of a blue mineral occurring in rounded fragments with a very slight pleochroism have been identified as blue tourmaline. These grains appear to be distinct from those described above as corundum.

The Cement.

From the beginning of the work considerable difficulty was experienced in determining the nature of the cement, which in thin section appeared merely as a blotchy aggregate. White mica and silica were the only minerals which could be identified with certainty. The remarkable clearness of the grains of quartz and the absence of a reddish colouring precluded the presence of iron oxide; and although both siliceous and carbonaceous materials were present, these formed only a small proportion of the cement.

When the powdered Pennant Sandstone was treated with hydrochloric acid a brisk effervescence immediately began, and increased on warming. The lime-water test proved this gas to be carbon dioxide. The solution on testing revealed the presence of both lime and iron, and the difficulty arose of proving that the iron, as well as the calcium, was originally in the form of a carbonate. After

a number of fruitless experiments, advantage was taken of the fact that a potash-alum solution dissolves calcite. Control experiments were carried out with calcite and siderite. Calcite proved to be soluble in a cold alum solution; siderite was insoluble, even after boiling and standing for forty hours. Hence it was concluded that an alum solution would dissolve the calcium carbonate from the original rock, and leave the iron carbonate—if present—behind.

A small quantity of the powdered sandstone was heated in an alum solution; an evolution of carbon dioxide began, thus demonstrating the presence of calcite. The solution, after being left for a day, was filtered and tested for iron, but none had been taken up from the rock. The residue was treated with dilute hydrochloric acid; an evolution of gas commenced, and the solution on testing revealed a relatively large proportion of iron. Attempts were made to estimate quantitatively the amount of calcium carbonate by this method; the average percentage was 2–2·3. Quantitative chemical analyses gave about 0·9 per cent calcium = 2·2 per cent calcium carbonate, thus demonstrating the fact that practically all the calcium carbonate had been removed by the alum solution.

Effects on Ignition.

The air-dried, powdered Pennant Sandstone was a greyish white before ignition. After ignition in an open crucible the powder changed to a pale salmon colour, forming a vivid contrast when placed side by side with the original powder. This change in colour was attributed to the calcination of the iron carbonate in the cement. The effects of ignition were still more strikingly demonstrated when the quartz grains from the original rock were mounted with grains from a sample which had been ignited and viewed under the microscope in reflected light. The former were clear, while the ignited grains were coated with a pellicle of iron oxide. Hence it was concluded that iron carbonate was present in the cement in relatively large quantity, in addition to calcite, secondary quartz, and carbonaceous material.

The Carbonaceous Material.

Carbonaceous matter was scattered throughout the rock in varying proportions, and generally in angular form. To eliminate any possibility of this black material being graphite, numerous fragments were placed on zinc and immersed in a copper sulphate solution. When placed under the microscope no coating of copper on the zinc was observed, and it was concluded that no graphite was present. Grains were treated with nitric acid and potassium chlorate, and then with ammonia. When mounted a few of these fragments yielded clear indications of plant structure. Portions of cuticle enveloping nodular masses were found. These may have been spore-cases; but were not so well defined as to be determined with certainty. Excellently well preserved specimens of woody tissue were present; the walls were relatively thick, and showed no signs of pitting, etc.

These fragments became more interesting when viewed between crossed nicols. The spaces between the walls were filled with a colourless mineral, which compensated with the quartz wedge, was insoluble in nitric acid, and gave the quartz polarization colours. It was concluded that this was quartz. This mineral did not exist as a mosaic, but a complete crystal of quartz filled each cavity.

The Conglomerates.

The bands of conglomerates appear mainly in the vicinity of the No. 2 Rhondda, although they occur locally at almost every horizon. In the Rhondda Valley near Ferndale there is a conglomerate consisting of ironstone and coal pebbles, quartzite pebbles, and plant remains replaced mainly by iron carbonate. Sometimes the conglomerates were overlaid by sandstones or lenticular coal-seams, and in places were immediately covered by sandy shales. Numerous pebbles from the conglomerates were sliced, but all were very similar, the most striking feature being the great proportion of large quartz pebbles, all of which were very strained, showing strong undulose extinction. These pebbles appear to have been derived from rocks which had been subjected to great earth movement, and at one time probably formed part of some pre-Cambrian ridge. Pebbles of shale, chert, sandstone, and quartzite have been found in these conglomerates.

The occurrence of coal pebbles is significant, and suggests that coal-seams were already undergoing denudation at this period. The cement of these conglomerates varies from almost purely recrystallized quartz to a sandy and carbonaceous matrix.

The Shales.

The shales, which occur at many horizons, may be described as sandy shales. They contain a large proportion of subangular quartz grains, and abundant white mica. They appear to contain a larger proportion of calcium and iron carbonates than the sandstones, and also more pyrrhotite, pyrites, sphærosiderite, corundum (?), zircon, and rutile. In addition to the forms described above, rutile needles have been found in the shales. Green pleochroic cleavage flakes of chlorite are abundant in every specimen examined. These shales are petrologically remarkably similar to the sandstones of the Pennants, except that the shales appear to contain a higher heavier mineral content. The heavy minerals are found concentrated in layers, different parts of the same specimen containing practically none, or abundant, heavy minerals.

The Clays.

Lenticular patches of clay have been found amongst the sandstones, particularly in a quarry due south of Caerphilly in the south crop. These reddish clays contain iron in the form of oxide, which can be observed under the microscope as a pellicle on the minute

quartz grains. The clay was thoroughly washed and decanted. Abundant chlorite similar to that of the sandstones was found, white mica in basal cleavage flakes, some rounded grains of zircon, and needles of rutile were relatively abundant. Neither pyrrhotite nor pyrites was found. Carbonaceous matter formed a large proportion of the material in the clay.

The Sandstones below the No. 2 Rhondda.

The sandstone below the No. 2 Rhondda coal-seam is exactly similar to that above, with the exception that fluorite, biotite, and sphærosiderite have not yet been found.

The presence of iron carbonate in the cement, a relatively large proportion of chlorite and pyrrhotite, together with chert as an original constituent, and large quantities of secondary silica, prove that lithologically these sandstones are identical with those above the No. 2 Rhondda.

Summary.

The occurrence of iron carbonate as a part of the cement in the Pennant Sandstone is not extraordinary, when the large amount of entombed organic matter is taken into consideration. The presence of organic material and the products of decay, the so-called humus acids, acting as reducing agents, would aid in the formation of iron carbonate and prevent its oxidation. Much of this carbonate probably owes its presence to a metasomatic replacement of calcium carbonate. The granules of siderite may have been derived from rocks similar to those of the Lower Coal Series of South Wales. The alkaline carbonates which hold the humic substances in solution would readily dissolve silica, thus becoming effective agents in the solution and redeposition of silica in the rock. A solvent of this kind would be formed by the impregnation of alkaline salts by carbonic acid.[1] The occurrence of so much secondary silica in the rock is probably the result of a redeposition of silica from such a solution. No oxides of iron have been found in any of the numerous separations, either by means of heavy liquids or the electro-magnet; their absence is easily explained when we consider the strongly reducing environment of the deposition and consolidation of the Pennant Sandstone. The perfectly rounded globules of sphærosiderite may have been precipitated whilst the sandstones were being deposited, but more probably derived from the denudation of fireclays similar to those of the Lower Coal Series of South Wales.[2] The dominant mineral chlorite, existing as perfect cleavage flakes, is entirely distinct from the secondary aggregates of chlorite in the rock, and was probably deposited in its present form. I have examined a powdered specimen of the Delabole Slates of Cornwall (Upper Devonian), and have found

[1] Clark, "Data of Geochemistry": *U.S. Geol. Surv.*, Bull. 616, 1916, p. 483.

[2] Gregory, *Proc. Royal Soc. Edin.*, vol. xxx, 1910, p. 359.

in it a large proportion of chlorite flakes, exactly like the detrital chlorite of the Pennant Sandstone. The very few flakes of biotite found show little trace of alteration. The paucity of heavy minerals indicates that the Pennant sediments had not a granitic source; they were mainly derived from pre-existing sediments which were rich in chert, had abundant chloritic material present, and yet were capable of furnishing fairly fresh biotite. Metamorphosed shales would account for the presence of cordierite and corundum.

The false-bedding of the sandstones, the occasional rapid alternation from conglomerate to sandy shale, and the entombment of large amounts of vegetable material in the strata suggest that the Pennant Sandstones were deposited under estuarine or lagoon conditions. The adjoining shores were probably covered with a rich vegetation which contributed material such as spore-cases, twigs, and branches to the waters of the lagoon.

The lenticular patches of detrital coal, and the conglomerates with ironstone and coal pebbles, points to the fact that areas of Lower Coal Measure age were undergoing denudation.

The Welsh Coal Series thickens considerably in a south-west direction, and reaches a maximum in south-west Glamorganshire. This increase in thickness is due, not only to a thickening of individual sandstone and shale bands, but also to a south-west incoming of fresh strata and more coal-seams.[1] This suggests that the source of the Pennant Series must be sought in that direction, i.e. south-west (approximately).

The lenticles of coal and shale, etc., which are formed through current bedding, have, in the majority of cases, a long axis in a north-east—south-west direction. Moreover, the steep side of each portion of false-bedding generally faces the north-east; apparently the currents which carried these sediments came from the south-west.

The Probable Source.

The great development of schalstein and spilites in Cornwall, beginning in the Middle Devonian and attaining a maximum in Lower Carboniferous times, was only a westward prolongation of a great mass of pillow lavas, extending from Moravia across the Rhine into England.[1] There is no reason to suppose that these spilites did not occur further westward than the Cornish shores, and as the spilitic suite of rocks are characteristic of geosynclinal action, it is probable that a land-mass extended parallel to this line of spilites, which were formed in a trough running approximately east and west.

Spilites are characteristic of continued subsidence, and do not accompany important uplift, yet those of Devon and Cornwall do not extend into a horizon higher than the Lower Carboniferous.[2]

[1] Strahan, in "The Country around Swansea": *Mem. Geol. Surv.*, 1907, p. 33.

[2] Jukes-Browne, *Stratigraphical Geology*, 1912, p. 309.

This probably indicates that the long subsidence from Ordovician times had finished, and that a crumpling of the geosyncline had begun before Middle Coal Measure times.

There is nothing in the Culm Measures to indicate the presence of Transition or Upper Coal Measures,[1] and it is possible that regions similar to these were undergoing denudation during Middle, Transition, and Upper Coal Measure times, contributing the quartz, chert, chlorite, mica, badly weathered felspars, etc., to form the Pennant Series.

The strike of both the bedding and cleavage of the Delabole Slates is north-west to south-east.[2] An anticlinal movement with an axis running approximately north-west—south-east would account for the similar direction of cleavage strike, and at the same time provide a shore line during early Coal Measure times, which would supply the material for the sediments of the Pennant Series.

The fact that the lowest horizon of the Pembrokeshire Coalfield as indicated by the fossil flora is one of Middle Coal Measure times (i.e. Lower Coal Measures are not represented by the Coal Series) suggests that the whole of the Coal Series of South Wales was formed subsequent to the crumpling of the geosyncline, which was initiated towards the end of the Lower Carboniferous period.

Conclusions.

(1) The sandstones below the No. 2 Rhondda coal-seam, east of the River Taff, are petrologically identical with the Pennant Sandstones. The lower boundary of the Pennant Series, east of the Taff, in my opinion, ought to be fixed, not at the No. 2 Rhondda, but at the base of these sandstones.

(2) The Pennants were deposited in a strongly reducing environment caused by decaying vegetable matter, probably under lagoon conditions.

(3) Their source was in a south-west (approximately) direction, and probably originated during uplift in early Coal Measure times, causing Carboniferous and Devonian rocks, and possibly some Pre-Cambrian ridge to be denuded.

(4) Up to the present I have been unable to obtain any satisfactory means of zoning these rocks by lithological characteristics, although when first mapping the area such a zoning appeared highly probable.

I have to express my indebtedness to Professor A. H. Cox, Ph.D., D.Sc., and to Professor O. T. Jones, M.A., D.Sc., for their valuable advice and criticism.

[1] Dewey & Flett, "British Pillow Lavas": Geol. Mag., 1911, p. 205.
[2] Howe, *Geol. of Building Stones* (Arnold), 1910, p. 299.

REVIEWS.

THE GEOLOGY OF THE BRITISH EMPIRE. By F. R. C. REED, M.A., Sc.D. 8vo., pp. viii + 480, with 12 folding maps and 13 maps and sections in the text. London: Edward Arnold. 1921. Price 40*s*.

THE title of this volume reminds one of the curious but unprofitable discussions as to the meaning of the word "empire". Can there be an empire without an emperor? There is an Emperor of India, but not an Emperor of England: is India then a part—or the whole—of the British Empire, and England not? But if the intention of the title is clear, such verbal subtleties do not concern us, and in this case there is only one respect in which any misapprehension can arise. No account of the geology of the British Isles is included. But we are not a logical race, and it is unlikely that any British geologist would think of referring to a Geology of the British Empire for a description of the geology of the British Isles. He would recognize that convenience is more important than logic. There are manuals of all sizes dealing with British geology, but information with regard to the geology of the outlying dominions is often difficult of access. It is for such information that he would look to a "Geology of the British Empire", and in the volume under review he would find it.

For purposes of reference the value of Dr. Reed's book is unquestionable. It has been carefully compiled and brought up to date. It is reasonably full and complete in all its parts, and its lists of references are ample. If a geologist wishes to find out what is known about a distant part of the British dominions he will discover it here more easily than anywhere else.

There is no pretence to originality. The author is not developing his own views: he is expounding those that are currently accepted. It might, perhaps, have been an advantage if he had been a little more critical, and had given some indication of the strength or weakness of the evidence; for in many cases the current opinion rests on a very slender foundation. This is exemplified even in India, where there has been a Geological Survey for considerably more than half a century. According to the official view the whole of the pre-Gondwana rocks of the Peninsula are of earlier date than the Cambrian. There is no real evidence in favour of this opinion, and the best that can be said for it is that there is no evidence against it. Dr. Reed hardly emphasizes sufficiently the extreme uncertainty of the correlation.

The amount of information that Dr. Reed has contrived to pack into his pages is enormous. It seems that everything is noticed. Occasionally, indeed, the notice is so slight that it becomes unintelligible to those who are not already acquainted with its subject. Thus the "cock-pits" of Jamaica are mentioned, but the term is not explained, and the very remarkable features of the cock-

pit country are scarcely even suggested. In general, however, the notices are as full as can reasonably be expected.

The chief defect of the work, if it can be considered a defect, is inseparable from its subject. The British Empire is not a geological unit. It consists of a number of fragments which belong, geologically, not to the British Empire, but each to its own surroundings. In the case of the larger areas this is no serious drawback, but in the case of the smaller ones the descriptions lose their point and interest because their connexions are not brought out. Dr. Reed has done his best to neutralize the defect. In describing the British West Indies, for instance, he gives a short account of the West Indies as a whole; but it is very brief, and is practically confined to an exposition of Suess's views on the subject. In several other regions it has not been possible to do even so much as this. Such a criticism, however, is directed not against the book itself but against its limits. Considered from a literary point of view the book lacks unity; considered as a work of reference it is like a single volume of an encyclopedia.

A work of praise is due to the maps. As might be expected at the present time they are not coloured, but nevertheless they are remarkably clear. The signs have been judiciously selected, and there is no attempt to show more detail than the method will bear. They will certainly save the reader a great deal of trouble, even if he is fortunate enough to have access to the originals on which they are based.

P. L.

Coal in Great Britain. By Walcot Gibson, D.Sc. pp. vii + 311, with viii plates and text-figures. London: Edward Arnold. 1920. 21*s*.

This book is an outgrowth from the author's work on *The Geology of Coal and Coal Mining*, and is to a very considerable extent a new book. The earlier chapters are taken from the older book, with many additions, but the chapters dealing with the geology of foreign coalfields have been omitted, while the descriptions of the British Coalfields have been extended and illustrated by a new series of clearly printed and well-designed maps showing their main structural features. The descriptions of the coalfields are admirable: they are very masterly examples of condensation, which, though devoid of superfluous or unessential matter, yet contain all the points necessary to render the descriptions clear and lucid. Criticism, however, may be passed on the methods of describing the positions of places, collieries, faults, etc. The maps, though clearly drawn and admitting of no doubt as to their meaning, are yet often of little immediate use in following the descriptions in the text. Place-names, often of obscure hamlets, bridges, and the like, are introduced freely with little or no indication of their approximate position, an omission which necessitates much prolonged

searching over any maps that may be to hand. The same applies to faults, which are quoted by the names by which they are known in their respective coalfields, names often taken from places not marked on any map of less scale than 6 inches to a mile, making their identification often a matter of some considerable length; and this is especially the case in the regions where no recent geological map has been published, since in these districts the fault lines and boundary lines on the published maps are frequently quite incorrect, and do not serve as any guide to the modern reading of the structure.

With this criticism, however, we may say that the book is one of great use both to students and to practical mining men, and one which fills a deeply felt want.

W. H. Wilcockson.

Imperial Institute Monographs on Mineral Resources: Coal. By J. H. Ronaldson, M.I.M.E., etc. pp. 166, with maps and diagrams. London: John Murray. 1920. 6*s*. net.

This monograph deals with the distribution of coal and the coal resources within the British Empire. The subject is a very large one, but the author has succeeded very well with his task, which has entailed an enormous amount of compression. The description of the coalfields is necessarily very brief, but the extent of the fields, so far as proved, the age, quality, and average thickness of the coals are stated, also the proved and probable resources of each area are tabulated. Each section is illustrated by a map, on which each coalfield mentioned in the text is clearly indicated by numbers, so that reference from the text to the map and back again can be readily made. These maps give a very good idea of the extent and distribution of the coalfields in the Dominions and the British Isles. Two graphs are given showing the coal outputs of the various countries of the world between 1865 and 1916. It is unfortunate that these are placed on opposite pages, for the scale of the first, dealing with the three largest producing countries, is only one-tenth of that of the second dealing with the countries of smaller output, and the result is that any one picking the book up casually might imagine that the output of Austria-Hungary was equal to that of the United States until he began to look more carefully at the scales. The real value of a graph is that it shows relationships of figures immediately to the eye, and it should not be necessary to look carefully for scales. However, the book should prove very useful for reference, particularly on account of its handy size and the clearness of its maps.

W. H. Wilcockson.